U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-265 351

# Demonstration of Aeration Systems for Poultry Wastes

**Manorcrest Farms, Camillus, N Y**

**Prepared for**

**Environmental Research Lab, Athens, Ga**

Oct 76

PB 265 351

EPA-600/2-76-106
October 1976

Environmental Protection Technology Series

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

# RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into five series. These five broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The five series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies

This report has been assigned to the ENVIRONMENTAL PROTECTION TECHNOLOGY series. This series describes research performed to develop and demonstrate instrumentation, equipment, and methodology to repair or prevent environmental degradation from point and non-point sources of pollution. This work provides the new or improved technology required for the control and treatment of pollution sources to meet environmental quality standards.

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

EPA-600/2-76-186
October 1976

# DEMONSTRATION OF AERATION SYSTEMS FOR POULTRY WASTES

by

J. H. Martin
R. C. Loehr
Cornell University
Ithaca, New York 14853

Project Number S800863

Project Officer

Lee A. Mulkey
Technology Development and Applications Branch
Environmental Research Laboratory
Athens, Georgia 30601

ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
ATHENS, GEORGIA 30601

## DISCLAIMER

This report has been reviewed by the Athens Environmental Research Laboratory, US Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the US Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

# ABSTRACT

A full scale study demonstrated the potential of aeration systems to reduce the water and air pollution potential of poultry wastes under commercial conditions. The performance of two oxidation ditches, each receiving the wastes from approximately 4000 laying hens, was monitored and evaluated.

The relationships between two design and operational variables and system performance were examined. The variables were level of oxygen supply and solids retention time. It was observed that an oxygen input equivalent to the exerted carbonaceous oxygen demand provided a high degree of odor control. Increase in oxygen supply to also satisfy the exerted nitrogenous oxygen demand resulted in nitrification which terminated ammonia desorption. Subsequent nitrogen losses were the result of denitrification relationships between removals of total solids, volatile solids, COD, and organic nitrogen in aerated poultry wastes were developed.

Two major problem areas were identified and examined. The first was the removal and concentration of residual solids to maximize oxygen transfer efficiency and minimize the volume of material requiring ultimate disposal. The second was sedimentation of solids in the oxidation ditch channel which reduced and in several instances stopped mixed liquor circulation.

The economics in terms of capital and operating costs of these systems were evaluated. Results indicated that the total cost of aeration would have increased egg production costs by a maximum of 4.9 percent in 1973.

This report was submitted in fulfillment of Project Number S800863 by Cornell University for Manorcrest Farms under the sponsorship of the Environmental Protection Agency. Work was completed December 1975.

# CONTENTS

Page

Abstract iii

List of Figures vi

List of Tables ix

Acknowledgements xii

Sections

I Conclusions 1

II Project Need and Objectives 3

III Theoretical Considerations 7

IV Investigative Facilities, System Design and Construction 27

V Methods and Materials 47

VI System Performance Results 56

VII Discussion of Experimental Results 113

VIII References 138

IX Appendices 146

## LIST OF FIGURES

| No. | | Page |
|---|---|---|
| 1 | Removal characteristics of total COD and suspended solids - semi-logarithmic plot (11) | 9 |
| 2 | Relationship between $\alpha$ and mixed liquor total solids concentration in aerated poultry wastes (37) | 25 |
| 3 | Aeration requirements in relation to mixed liquor total solids and $C_L$ (37) | 26 |
| 4 | Location and site plan of Manorcrest Farm No. 2 | 28 |
| 5 | Plan view, Building No. 1, before modification | 29 |
| 6 | Cross section, A-A', Building No. 1 | 30 |
| 7 | Floor plan and analytical laboratory in the Cornell Agricultural Waste Management Laboratory | 33 |
| 8 | Plan view of oxidation ditches and settling tanks | 35 |
| 9 | Location of velocity measurements, plan view | 49 |
| 10 | Location of velocity measurements, cross section | 49 |
| 11 | Comparison of oxygen transfer characteristics, Thrive Centers cage rotors | 63 |
| 12 | Observed relationships between SRT and removal of total and volatile solids | 68 |
| 13 | Observed relationships between SRT and removal of organic nitrogen and COD | 68 |
| 14 | Nitrogen transformations during the start-up period, Ditch II | 74 |
| 15 | Reoccurrrence of nitrite accumulation in Ditch II | 76 |
| 16 | Dissolved oxygen concentrations in Ditch I at the oxygen transfer capacity of 351 gms $O_2$/1000 bird-hours | 77 |
| 17 | Mixed liquor concentrations of total and free ammonia plus pH at the oxygen transfer capacity of 351 gms $O_2$/1000 bird-hours | 79 |

LIST OF FIGURES continued

| No. | | Page |
|---|---|---|
| 18 | Mixed liquor concentrations of total and free ammonia plus pH at the oxygen transfer capacity of 520 gms $O_2$/1000 bird-hours | 82 |
| 19 | Dissolved oxygen concentrations in Ditch I at the oxygen transfer capacity of 520 gms $O_2$/1000 bird-hours | 83 |
| 20 | Dissolved oxygen concentrations in Ditch II at the oxygen transfer capacity of 815 gms $O_2$/1000 bird-hours | 84 |
| 21 | Dissolved oxygen concentrations in Ditch II at the oxygen transfer capacity of 790 gms $O_2$/1000 bird-hours | 84 |
| 22 | Comparison of mixed liquor and settling tank overflow total solids concentrations at MLTS concentration below 12,000 mg/ℓ | 87 |
| 23 | Comparison of mixed liquor and settling tank overflow total solids concentrations at MLTS concentration above 18,000 mg/ℓ | 87 |
| 24 | Typical results from a batch settling test, aerated poultry wastes | 88 |
| 25 | Zone settling velocity versus total solids concentration in aerated poultry wastes | 89 |
| 26 | Sludge volume index versus total solids concentration in aerated poultry wastes | 91 |
| 27 | Vertical section through a basic single deck, 18 inch Sweco Vibrating Screen Separator | 93 |
| 28 | Illustration of average material travel on the screen | 93 |
| 29 | Assembly diagram of a Thrive Centers cage rotor | 97 |
| 30 | Sediment profile in Oxidation Ditch II, 1973-74 | 100 |
| 31 | Sediment profile in Oxidation Ditch I, 1973-74 | 100 |

## LIST OF FIGURES continued

| No. | | Page |
|---|---|---|
| 32 | Sediment profile in Oxidation Ditch I, 1974-75 | 102 |
| 33 | Sediment profile in Oxidation Ditch II, 1974-75 | 102 |
| 34 | Cross section of a Hart Cup | 105 |
| 35 | Observed relationship between SRT and removal of total solids in aerated poultry wastes | 115 |
| 36 | Observed relationship between SRT and removal of volatile solids in aerated poultry wastes | 115 |
| 37 | Observed relationship between SRT and removal of COD in aerated poultry wastes | 116 |
| 38 | Observed relationship between SRT and removal of organic nitrogen in aerated poultry wastes | 116 |

# LIST OF TABLES

| TABLE | TITLE | PAGE |
|---|---|---|
| 1 | Egg Production Flock Number and Size Changes, U.S. | 4 |
| 2 | Observed Total and Volatile Solids Destruction, Percent, as Related to Poultry Waste Stabilization Time | 10 |
| 3 | TKN Concentration, Percentage of Total Solids in Animal Wastes | 11 |
| 4 | Nitrogen Losses from Aerated Poultry Wastes Attributed to Denitrification | 14 |
| 5 | Assumed Fresh Poultry Manure Characteristics | 36 |
| 6 | Kinetic Coefficients and $\theta_c^m$ Used for Project Oxidation Ditch Design | 39 |
| 7 | Expected Treatment Efficiencies of Aerobic Poultry Wastes Stabilization at a 20 Day SRT | 39 |
| 8 | Design Estimates of Oxygen Requirements | 40 |
| 9 | Design Values for Sludge Storage Time | 42 |
| 10 | Oxygenation Capacity for the Thrive Center Cage Rotor | 45 |
| 11 | An Outline of the Manorcrest Demonstration Activities | 56 |
| 12 | Summary of Initial Operating Conditions, September, 1973 | 57 |
| 13 | Changes in Operating Conditions | 58 |
| 14 | Results of Oxygen Transfer Measurements - Ditch I | 60 |
| 15 | Results of Velocity Measurements - Ditch I | 61 |
| 16 | Results of Oxygen Transfer Measurements - Ditch II | 62 |
| 17 | Results of Velocity Measurements - Ditch II | 62 |
| 18 | Raw Manure Characteristics, Manorcrest Farms | 65 |
| 19 | Comparison of COD Removed with Oxygen Supply | 70 |

## LIST OF TABLES continued

| TABLE | TITLE | PAGE |
|---|---|---|
| 20 | Dissolved Oxygen Concentrations | 71 |
| 21 | Observed Removal of Soluble COD | 72 |
| 22 | Relationships Between Oxygen Transferred and Removal Efficiencies of Organic and Total Nitrogen | 78 |
| 23 | Change in Mass of Ammonia Nitrogen in Ditch I at 351 gms $O_2$ Transferred/1000 Bird-hours | 80 |
| 24 | Results of Centrifuge Test | 90 |
| 25 | Relationship Between Lead Angle and Performance 200 Mesh Screen, 0.074 mm | 94 |
| 26 | Results of Single and Two Stage Screening Trials | 95 |
| 27 | Comparison of Initial Ditch Velocities at Volumes of 68,877 ℓ and 105,980 ℓ | 101 |
| 28 | Sediment Characteristics | 101 |
| 29 | Initial and Annual Capital Costs, Manorcrest Project Aeration Systems Components | 108 |
| 30 | Total and Annual Capital Costs for the Manorcrest Aeration System | 109 |
| 31 | Energy Costs for Aeration in Relation to the Level of Oxygen Transfer | 110 |
| 32 | Operating Costs for Manorcrest Aeration Systems per 1000 Hens per Year | 111 |
| 33 | Cost Summary of Aeration of Poultry Wastes, Manorcrest Farms | 112 |
| 34 | Comparison of the Physical Details of Manorcrest Ditch II and an Oxidation Ditch Discussed by Windt et al. | 128 |
| 35 | New York State Egg Production Costs | 132 |

## LIST OF TABLES continued

| TABLE | TITLE | PAGE |
|---|---|---|
| 36 | Comparison of Capital Costs per 1000 Birds, Manorcrest Farms and Houghton's Poultry Farm | 134 |
| 37 | Effect of Power Costs for Aerobic Stabilization on Egg Production Costs | 136 |
| 38 | Effect of Total Costs for Aerobic Stabilization on Egg Production Costs | 136 |

## ACKNOWLEDGEMENTS

This research was supported by the Environmental Protection Agency under project number S800863; Manorcrest Farms, Camillus, New York; and the College of Agriculture and Life Sciences, Cornell University. The guidance of Mr. Lee Mulkey, Environmental Protection Agency, Athens, Georgia who served as the project officer is gratefully acknowledged.

Most sincerely appreciated are:

- The contributions of Mr. and Mrs. Earl Hudson and the personnel of Manorcrest Farms,
- The technical assistance of Lorraine Marnell and Charles Barton,
- The help of R.J. Krizek and J.F. Gerling in preparation of the figures,
- The patience and skill of Sue Giamichael in typing the report.

# SECTION I

# CONCLUSIONS

1. Properly designed aeration systems for poultry wastes will provide excellent control of odors as well as removal of COD, total and volatile solids, and nitrogen.

2. The process can be utilized to meet individual waste management objectives such as odor control, odor control and nitrogen removal via nitrification-denitrification, or odor control and possibly nitrogen conservation.

3. Odor control can be achieved by satisfying the exerted carbonaceous oxygen demand. The quantity of oxygen transferred to achieve odor control was 351 gms $O_2$ per 1000 bird-hours.

4. Removal of total and volatile solids and COD, increase with solids retention time (SRT).

5. Removal of soluble COD exceeded 85 percent at SRT's of 10 days or longer.

6. The potential for nitrogen removal is controlled by the ammonification of organic nitrogen which is also a function of SRT.

7. Losses of nitrogen will occur via ammonia desorption or nitrification-denitrification in oxidation ditches. The removal mechanism is dependent on the level of oxygen supply. Observed losses ranged from 48.8 to 63.3 percent of nitrogen loading.

8. Complete oxidation of ammonia with simultaneous denitrification occurred at the oxygen transfer level of 520 gms $O_2$ per 1000 bird-hours. This slightly exceeded the calculated, exerted carbonaceous and nitrogenous oxygen demand.

9. The potential for nitrogen conservation by storage in the $NO_3$-N form is unclear but oxygen requirements are high. Favorable conditions for denitrification make the practicality of this approach questionable.

10. Control of mixed liquor total solids concentrations is desirable to optimize system performance. No conclusions could be drawn as to the best method of liquid-solid separation with aerated poultry wastes. Both gravitational settling and centrifugation appear to have potential, but additional study is necessary.

11. Sediment accumulations in oxidation ditches due to improper physical design can result in process failure. Improved hydraulic design can help overcome this problem.

12. The use of aeration systems for poultry wastes will increase egg production costs. Energy cost for odor control was $0.0033 per dozen eggs which represents a 0.8 percent increase in 1973 New York egg production costs. Total cost was $0.0167 per dozen eggs or 3.8 percent increase in production costs. Although these costs appear reasonable, further opportunities for reduction exist.

# SECTION II

# PROJECT NEED AND OBJECTIVES

## PROJECT NEED

Significant changes in the efficiency of commercial egg production have occurred in the past 20 years. The result is an increasingly intensive industry with fewer commercial egg farms and higher numbers of laying hens per farm. Data for the years 1964 and 1969 (Table 1) show this trend. Today (1975), the minimum size of an economically viable unit is about 30,000 birds if egg production is the only source of income. Larger operations are the rule rather than the exception with the largest farms containing 300,000 to 500,000 hens. The gains in efficiency in egg production have been accompanied by serious problems in the area of waste management. The satisfactory disposal of poultry wastes is necessary for both environmental protection and successful egg production.

Perhaps the most important factor in the development of commercial egg production as it exists today was the change from the floor to the cage management system. As the name implies, the floor system consisted of hens unconstrained on the floor of pens. Sawdust, straw or some similar material was placed on the pen floor, and the accumulated manure mixed with this material. The result, termed litter, provided a medium for stabilization through drying and a degree of biological activity. It also provided a storage mechanism for periods of up to 12 months.

The floor or litter system had two disadvantages which resulted in the conversion to the cage management system. One, the cage system allowed an increase in bird density which lowered capital costs per hen. The minimum floor area per bird in a floor system was about 0.19 square meters (2 square feet). At higher densities, the litter could not be kept dry. Dirty eggs and disease problems resulted. Conversion to the

## Table 1. EGG PRODUCTION FLOCK NUMBER AND SIZE CHANGES, U.S. (1)

| | 1964 | | | 1969 | | |
|---|---|---|---|---|---|---|
| | Chickens on hand, 4 months old and over | | | Chickens on hand, 3 months old and over | | |
| | Number of farms (1,000) | Percent of farms | Percent of birds | Number of farms (1,000) | Percent of farms | Percent of birds |
| Under 100 | 896.2 | 73.7 | 7.3 | 337.7 | 71.7 | 2.7 |
| 100 - 3,199 | 300.9 | 24.7 | 30.7 | 115.1 | 24.4 | 10.8 |
| 3,200 - 9,999 | 12.9 | 1.1 | 21.0 | 9.2 | 2.0 | 14.9 |
| 10,000 and over | 5.8 | 0.5 | 41.0 | 8.9 | 1.9 | 71.6 |
| | 1,215.8 | 100.0 | 100.0 | 470.9 | 100.0 | 100.0 |

cage system reduced floor area per bird to about 0.04 square meters (0.45 square feet).

The second disadvantage of the floor system was its high labor requirement. The cage system permitted the mechanization of feeding, egg collection, and manure handling, thus reducing manual labor requirements. With the floor system, one man could care for approximately 5,000 birds. Today, with cages, one man can handle from 35,000 to 50,000 hens.

The adoption of new management techniques resulted in changes in both physical waste characteristics and the nature of poultry farms. With the increase in bird density, the natural drying and stabilization which was a characteristic of the floor system no longer occurred. The raw waste which has a moisture content of about 75 percent wet basis, was collected in pits beneath the cages. Due to the semi-solid nature of the waste, liquid manure handling techniques were possible. Additional water was normally added either directly or via water spillage to create a pumpable slurry. Liquid manure systems were attractive because the physical labor associated with manure handling was reduced.

The shift to liquid manure storage and handling techniques created an ideal environment for uncontrolled, anaerobic microbial activity. Such activity results in objectionable odors which are exhausted through ventilation fans and are dispersed when the wastes are disposed of on the land. The odors consist of malodorous mercaptans, amines, volatile acids, and sulfides. Odor problems related to poultry farms have resulted in legal and administrative actions by a number of state environmental agencies.

The trend towards intensification in the egg industry has been accompanied by specialization. Many farms, especially the larger operations, purchase some or all the feed required. Therefore, land for the production of feed is not necessarily a part of these farms. In many instances purchase of feed may present economic advantages. The result can be heavy waste loadings on small areas which intensifies the potential for water pollution. Of particular concern is the loss of nitrogen to both surface and groundwaters. Numerous studies (2,3,4) have shown that nitrogen is the limiting parameter in the disposal of animal wastes to the land.

Aerobic biological treatment processes have the potential to eliminate odor problems associated with poultry wastes (5,6), provide an innocuous method for nitrogen removal when required, and provide waste stabilization through the removal of readily biodegradable organic compounds. Experiences with oxidation ditches have indicated they are an aerobic treatment process that can accomplish these benefits and be a feasible treatment unit for poultry wastes.

## OBJECTIVES

Although laboratory and pilot plant investigations have provided a great deal of information about the application of aerobic biological processes to poultry wastes, the feasibility under full scale commercial conditions has been unclear. The objective of this project was to establish an aerobic biological treatment system on a commercial poultry farm in order to:

1) Demonstrate and evaluate the potential of aerobic treatment to reduce the air and water pollution potential of poultry wastes under commercial conditions.
2) Identify problem areas in the design and operation of these systems and evaluate possible solutions to these problems.
3) Evaluate the economic impact of aerobic treatment of poultry wastes.
4) Develop operating procedures which will serve as guidelines for commercial applications.

# SECTION III

# THEORETICAL CONSIDERATIONS

## INTRODUCTION

The use of aerobic biological processes for the stabilization of animal wastes such as poultry manure has been preceded by their application to domestic and industrial wastes. However, the process fundamentals are independent of the type of waste undergoing treatment. Therefore, basic information derived from domestic and industrial waste treatment studies can be applied in the biological treatment of animal wastes. However, for the rational use of fundamental concepts developed from domestic and industrial wastewater treatment, differences in treatment objectives and waste characteristics should be recognized.

Normally, domestic and industrial wastewaters are discharged to surface waters. This requires high levels of removal of both oxygen demanding and nutrient compounds. In contrast, the effluent guidelines for the feedlot industry (7) state that animal wastes should not be discharged to watercourses. This is in keeping with the historic practice of returning animal manures to the land. The use of the land for ultimate disposal changes the treatment objectives. In light of the waste stabilization capacity of soils, emphasis in animal waste treatment is on the removal of the oxygen demanding and nutrient fractions which are susceptible to movement to both surface and groundwaters. Achievement of these objectives will provide the necessary control of odors.

The characteristics of animal wastes subjected to biological treatment differ significantly from conventional municipal and industrial wastes. Animal wastes have both greater oxygen demand and higher solids concentrations. Removal of settleable solids prior to treatment is not necessary.

High solids loadings are a characteristic of aerobic treatment units for animal wastes. Since these units are normally operated at relatively long solids retention times (SRT's), the process is comparable to combined activated sludge and aerobic digestion.

With the recognition of these differences, many of the principles which have been developed in studies of conventional biological waste treatment can be successfully applied to animal waste treatment. This will provide a more rational approach to the design and operation of animal waste treatment systems and result in more reliable and efficient operation.

## POULTRY MANURE - CHARACTERISTICS AND TRANSFORMATIONS

Raw poultry excreta is a complex substrate containing soluble and particulate inorganics and organics. The organic fraction contains carbonaceous and nitrogenous components which vary in their rate of biodegradability. The non-biodegradable inorganic or fixed solids constitute about 20 to 28 percent by weight of poultry manure total solids (8,9,10). Phosphorus, calcium, and chlorides are the major components of fixed solids (10). This is an expected result since both calcium and phosphorus are fed at levels in excess of the birds physiological needs to insure adequate uptake. Although the percentage of fixed solids will vary with feeding practices, 25 percent appears to be a reasonable average estimate.

Due to the complex nature of the organic fraction, substrate utilization rates for the various components vary significantly. In a batch study involving the non-settleable components of a poultry manure suspension, three distinct COD removal rates over a 20 day period were observed (Figure 1). The most rapid removal of COD occurred during the first 10 days of treatment. Additional removal results from utilization of the more slowly biodegradable compounds. Degradation of soluble organic matter appears more rapid than that of particulate material. The removal of suspended solids followed a similar pattern, although two rather than three removal rates were observed (Figure 1).

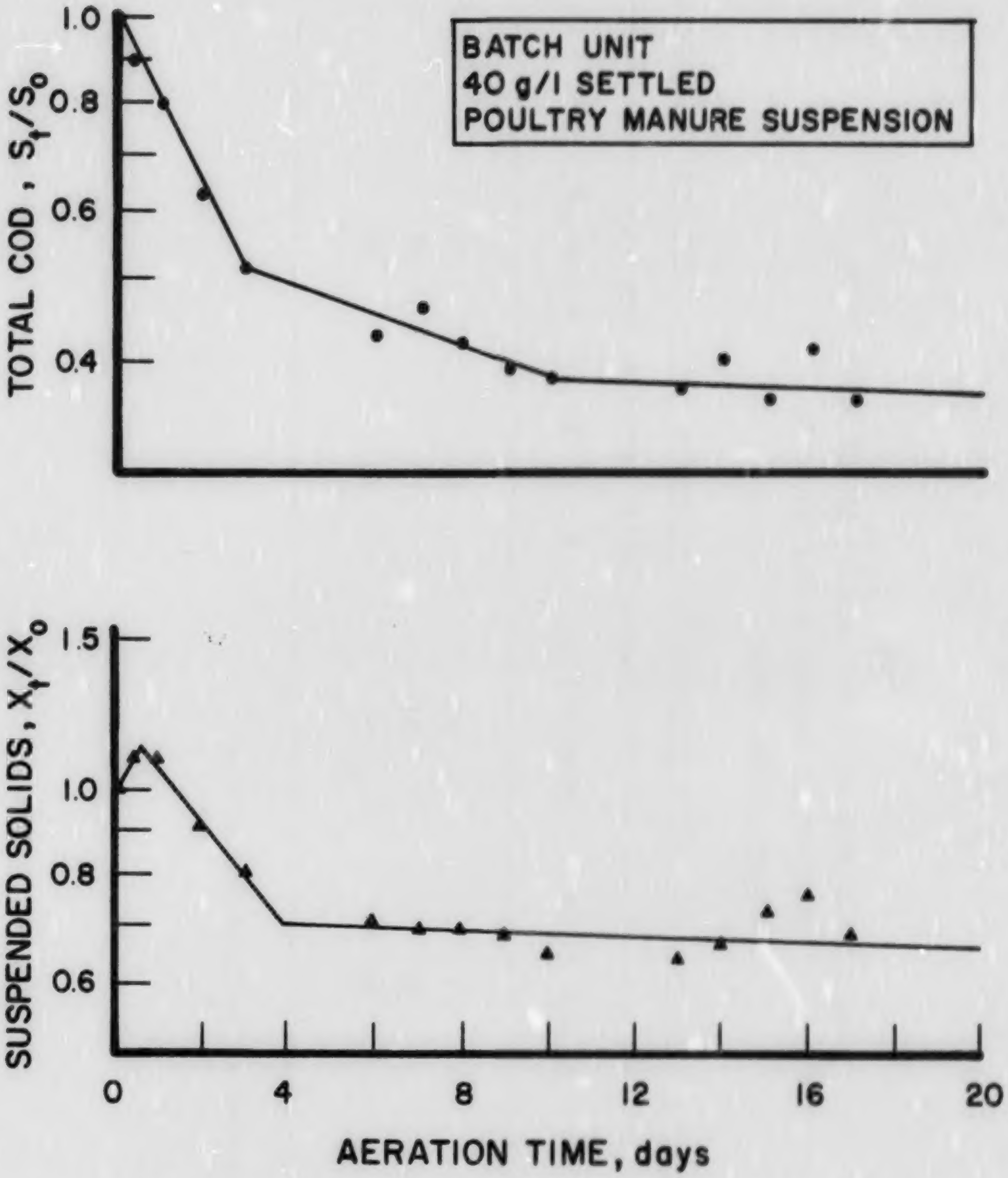


Figure 1. Removal characteristics of total COD and suspended solids - semi-logarithmic plot (11)

Table 2. OBSERVED TOTAL AND VOLATILE SOLIDS DESTRUCTION PERCENT, AS RELATED TO POULTRY WASTE STABILIZATION TIME

| | Average Solids Retention Time | | | | |
|---|---|---|---|---|---|
| Parameter | 12 days (12)* | 36 days (12) | 4.5 mo (6) | 6.5 mo (9) | 7.5 mo (9) |
| Total solids | 27 | 47 | 53 | 43 | 42 |
| Volatile solids | 35 | 64 | 63 | 56 | 54 |
| COD | 26 | 51 | 63 | 60 | -- |

*Numbers in parentheses indicate data source

The removal of total and volatile solids and COD with time observed by various investigators is presented in Table 2. These data were collected from both pilot and full scale oxidation ditches. The 12 and 36 day results were collected from a continuous flow system, whereas the other data were obtained from continuously loaded batch systems. The comparison indicates that little additional removal of solids or COD occurs when time of treatment is extended beyond 36 days. An important factor is that approximately 50 percent of the total solids added to the system remains as residual solids following treatment. This results in a continuous increase in total solids concentration in a continuously loaded batch system.

An important characteristic of poultry manure is the concentration of nitrogen. In comparison to the wastes of other major agricultural species of domestic animals, poultry excreta contains the highest concentration of nitrogen (Table 3).

Table 3. TKN CONCENTRATION, PERCENTAGE OF TOTAL SOLIDS IN ANIMAL WASTES

| | Beef | Dairy | Swine | Poultry |
|---|---|---|---|---|
| TKN, % of T.S. | 1.9 (13)* | 4.9 (14) | 3.4 (15) | 8.4 (16) |

*Numbers in parentheses indicate data source

The nitrogen in poultry manure is in the form of proteins and uric acid. About 65 to 75 percent of the TKN in fresh poultry wastes is in the form of uric acid (17). This nitrogen undergoes transformation during waste storage and stabilization. Both proteins and uric acid can be converted to ammonia under aerobic and anaerobic conditions. Uric acid results in urea which in turn is converted to ammonia. These reactions can be combined under the term ammonification and expressed as:

$$\text{Organic Nitrogen} \xrightarrow{\text{Ammonification}} NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^- \quad (1)$$

Ammonification results in an increase in pH due to ionization of $NH_4OH$. If ammonium concentrations and pH are sufficiently high, ammonia volatilization will occur.

Under aerobic conditions, ammonia nitrogen can be microbially oxidized to nitrite and nitrate nitrogen. The two groups of microorganisms primarily responsible for this transformation are Nitrosomonas and Nitrobacter. The oxidation of $NH_4^+$ to $NO_3^-$ is a two step process termed nitrification and can be expressed as follows:

$$NH_4^+ + 3/2\ O_2 \xrightarrow{\text{Nitrosomonas}} NO_2^- + 2H^+ + H_2O \quad (2)$$

$$NO_2^- + 1/2\ O_2 \xrightarrow{\text{Nitrobacter}} NO_3^- \quad (3)$$

Nitrification studies have indicated that 50 to 60 percent of the initial TKN in poultry wastes could readily be nitrified. Therefore, 50 to 60 percent of the initial organic nitrogen was easily converted to ammonia, since the fresh manure contains only trace amounts of ammonia.

Nitrifying organisms and hence nitrification can occur in natural waters and soils as well as in waste treatment systems. The process results in the exertion of a nitrogenous oxygen demand (NOD) which is important in both natural waters and waste treatment systems. In poultry manure, the NOD is significant being equal to approximately 25 percent of the chemical oxygen demand of the waste.

Under anaerobic conditions, nitrite and nitrate nitrogen can be reduced to nitrogen gas ($N_2$) or nitrogen oxides ($N_2O$ or NO) by denitrifying microorganisms. The combined processes of nitrification-denitrification can result in significant nitrogen removal from aerated poultry wastes. Some observed nitrogen losses from aerated poultry wastes attributed to denitrification are presented in Table 4.

## PROCESS DESIGN

### General

The design criteria for aerobic treatment of animal wastes suggested by Jones et al. (21) has served as the standard basis of design for these systems. Both the Midwest Plan Service and the Canada Department of Agriculture suggest this method of process design (22,23). These design criteria are empirical based upon studies involving swine and dairy cattle wastes. System volume is determined using the organic loading rate concept. The recommended loading rate is 0.5 kg $BOD_5/m^3$/day (0.03 lbs $BOD_5/ft^3$/day). The suggested parameter for oxygen requirement is twice the daily $BOD_5$ loading assuming that in the stabilization unit, the aeration system will transfer 80 percent of the amount it will transfer in tap water.

Although many systems developed from these empirical parameters have performed satisfactorily, this approach has several disadvantages. It is difficult to extrapolate between different wastes and environmental conditions. Reasons for process failures are unclear since the design and operation of the system is not based on process fundamentals. Possibly the greatest liability of the empirical approach is its inflexibility. No opportunity exists to adjust the degree of waste stabilization to specific requirements. This is especially significant when only a minimal degree of stabilization is required.

This organic loading rate concept represents an early approach to slurry type biological treatment system design. A more fundamental approach was developed from the observation that effluent quality was related to the ratio of substrate loading (F) per unit time and the mass of microorganisms (M).

Table 4. NITROGEN LOSSES FROM AREATED POULTRY WASTES ATTRIBUTED TO DENITRIFICATION

| System Type | Dissolved Oxygen, mg/ℓ | Nitrogen Loss, % | Reference |
|---|---|---|---|
| Oxidation Ditch | 2 - 7 | 36 | 6 |
| Oxidation Ditch | 2 - 6 | 66 | 9 |
| Diffused Aeration Basin | 0 - 2 | 50-60 | 18 |
| Oxidation Ditch | 0 - 6 | 70-80 | 19 |
| Oxidation Ditch | * | 30-90 | 20 |

*Intermittent to continuous aerator operation

As the substrate loading increased, effluent quality deteriorated. Based upon these observations, the food to microorganism (F/M) ratio was established as a design parameter for biological treatment processes (24). Owens et al. (25) have investigated the effects of different F/M ratios on effluent quality in the aerobic treatment of swine wastes. Their observations of decreasing effluent quality at increasing F/M ratios concurred with results of previous studies.

Although the F/M concept is fundamentally sound, it is difficult to use due to problems in determining concentrations of active microorganisms. Traditionally, volatile suspended solids concentrations (VSS) have been used to estimate active mass. Due to high concentrations of VSS present in raw poultry manure, this method of estimation has little significance in poultry wastewaters.

Other design approaches have been developed based upon microbial kinetics using first order substrate utilization kinetics. These approaches can be applicable to poultry wastes (11).

Another kinetic approach has used a Monod (26) type equation as the basis of a treatment model. This approach relates microbial growth to a limiting substrate concentration. Substrate limited growth appears a more precise description of conditions in biological waste treatment systems than the first order substrate utilization approach. Practical application of this approach (27) utilizes the biological solids retention time, $\theta_c$, as the unifying design parameter in that all system variables can be related to it. Mathematically, $\theta_c$ can be represented as

$$\theta_c = \frac{X_T}{\left(\frac{\Delta X}{\Delta t}\right)_T} \tag{4}$$

where $X_T$ = total active microbial mass in treatment system, mass.

$(\Delta X/\Delta t)_T$ = total quality of active microbial mass leaving the system in a unit of time, mass per time.

As $\theta_c$ increases, the effluent concentration of the growth limiting substrate will decrease. The microorganism concentration is a function of the available substrate concentration and $\theta_c$. Excess microorganism production is also related to $\theta_c$. As $\theta_c$ increases, the excess microorganism production will decrease due to endogenous respiration.

This latter approach is not unlike the F/M approach. When a value for the microorganism concentration is specified in the F/M approach, a value for $\theta_c$ is specified implicitly but not explicitly. The F/M and $\theta_c$ design approaches have been compared in a treatability study of an oil refinery wastewater (28) and found to produce similar designs.

The design equations for most approaches have been developed based on studies involving liquid wastes. Although the equations are fundamental to all biological systems, detailed application to a waste such as poultry excreta is difficult. One factor is the high solids concentration of the poultry waste. Whereas the influent solids concentrations of municipal and certain industrial wastes are small in comparison to concentrations in the treatment system, the reverse can be true with poultry and other animal wastes. This complicates determination of kinetic coefficients which depend on measurement of volatile suspended solids to estimate cell mass.

A second problem is introduced due to the complex nature of the waste. Due to the composition of these wastes, the single substrate hypothesis is not directly applicable. In waste treatment, it is normally assumed that the limitation of total biodegradable material controls microorganism population. Due to the limitations of the BOD determination, COD is commonly used to estimate biodegradable compounds. However, the COD test measures both biodegradable and non-degradable compounds which are subject to chemical oxidation. Therefore, it is necessary to estimate the biodegradable portion of COD. This approach was used (29) to model the aerobic treatment of swine wastes. However, the biodegradable fraction is a function of time of treatment due to the different substrate utilization rates for different fractions of the organic matter. Therefore, estimation of the biodegradable fraction is a function of the time of treatment and vice versa.

Although there are inherent difficulties in the detailed application of substrate limited approach (27) to the aerobic treatment of poultry and other animal wastes, it provides a rational basis for relating treatment efficiency to $\theta_c$. In this context, treatment efficiency expressed as removal of COD, total and volatile solids, and/or degradation of organic nitrogen can be related to and controlled by manipulation of $\theta_c$. Changes in both COD and organic nitrogen removal have been related to $\theta_c$ in aerobically treated poultry wastes (16).

Determination of $\theta_c$ as defined in Equation (4) requires measurement of active biomass. However, assuming complete mixing resulting in the uniform distribution of microorganisms, the solids retention time (SRT) of the solids can be used to estimate $\theta_c$. SRT is the theoretical time that solids are retained in the treatment system and can be expressed as

$$\text{SRT} = \frac{\text{wt of solids in the system}}{\text{wt of solids leaving the system/time}} \qquad (5)$$

$\theta_c$ is a function of the active biomass in a system while SRT can be determined by measuring other forms of solids such as volatile, suspended, total suspended, or total solids. If the system is completely mixed, SRT is a reasonable estimate of $\theta_c$ and is the key factor in the utilization of this approach. The unifying parameter, SRT, can be estimated by utilizing an easily determined parameter, solids concentration.

Both biochemical oxygen demand (BOD) and chemical oxygen demand (COD) tests are methods which provide an indirect measure of available substrate in terms of the oxygen equivalent of organic matter. An advantage of the BOD determination is that unlike the COD test it includes only organic matter susceptible to biological degradation. However, the BOD test is dependent on both the time period and initial seed. It may or may not include nitrogenous oxygen demand (NOD) depending on the presence or absence of nitrifying microorganisms. This presents difficulties in comparing the results from raw and treated waste samples.

The COD test is an alternative. Although this approach includes organic matter not susceptible to biological degradation, it does not include the NOD of ammonia nitrogen. If nitrites are present, they will be chemically oxidized to nitrates. Correction for this factor is simple requiring only concurrent determination of the nitrite concentration in the sample.

Neither test is ideal but in a situation where change across a treatment system is being measured, COD appears to have an advantage. By assuming that a change in COD is due completely to biodegradation, concern with the non-biodegradable fraction of COD is eliminated. Theoretically, the change in COD can be considered equal to the change in BOD.

Another advantage of the COD test is the relatively short analysis time required in comparison to BOD determinations. Results of COD analyses are available in less than three hours, whereas the BOD test requires a minimum of five days. For these reasons, further discussion will focus on COD rather than BOD.

## CHEMICAL OXYGEN DEMAND

The requirement for removal of COD in the aerobic treatment of poultry manure is a function of the place of ultimate disposal, the land or surface waters. As noted earlier, the land is the most logical site for ultimate disposal of these wastes. In this context, the significance of COD removal is changed. The land has the ability to stabilize the organic carbon in poultry wastes at application rates of dry solids up to 101 metric tons/ha/yr (45 tons/ac/yr) (2). Loading rates of this magnitude were shown to be excessive in terms of nitrogen. Therefore, at acceptable application rates of nitrogen, high levels of COD removal do not appear necessary.

The importance of COD removal in the aerobic treatment of poultry wastes lies in two areas: odor control and removal of soluble organics which are subject to transport in surface runoff. To provide odor control, the exerted COD must be satisfied aerobically. Otherwise, the biologically available COD will be utilized as substrate by anaerobic organisms with the production of malodors. The soluble COD fraction is the most readily available substrate (11) in poultry wastes. Therefore, the oxygen required for odor control will also reduce the soluble organics in the effluent.

The COD of fresh poultry excreta includes both biodegradable and non-biodegradable compounds. In addition, the test does not distinguish between rapidly and slowly biodegradable compounds. However, oxygen requirements can be related to COD removal, i.e., exerted oxygen demand.

The following general equation describes the rate of oxygen utilization for the oxidation of carbonaceous matter:

$$\frac{do}{dt} = Y \left(\frac{df}{dt}\right) + b \cdot c \cdot X \qquad (6)$$

where $\frac{do}{dt}$ = rate of oxygen utilization

$\frac{df}{dt}$ = rate of substrate utilization

$Y$ = coefficient to convert substrate units to oxygen units

$b$ = microbial decay coefficient

$c$ = coefficient to convert cell mass to oxygen units

$X$ = microbial cell concentration

Since both terms, substrate utilization and endogenous respiration, are manifested as COD removed, Equation 6 can be rewritten as:

$$\frac{do}{dt} = \frac{d[COD]}{dt} \tag{7}$$

COD removal in aerated poultry wastes is a function of time of treatment, i.e., SRT (11,16). The required degree of stabilization, hence COD removal, can vary for individual situations. This variation is related to possible storage of effluent and possible odor problems during final disposal. Another factor is the potential for surface runoff. By the control of SRT, COD removal can be matched with overall waste management objectives and is a rational approach to estimate carbonaceous oxygen requirements.

## NITROGEN

The objective of nitrogen management in aeration of poultry wastes is a function of the overall farm operation. As previously discussed, a poultry farm may or may not engage in crop production. Where crop production is involved, nitrogen conservation, to the extent that the nitrogen can be recycled through a crop, is a logical objective. Conversely, nitrogen removal can be necessary when productive land for ultimate disposal is limited.

The best approach for nitrogen conservation in aeration systems will depend on the quantity of available land and on the nitrogen management objectives of the poultry operation. A number of possible approaches exist. One involves nitrification which was described earlier.

Although several groups of microorganisms are capable of nitrification, two groups of autotrophs, Nitrosomonas and Nitrobacter, are of primary importance in wastewaters. The first step of the process releases hydrogen ions with a resultant depression in pH.

Nitrification is an aerobic process requiring oxygen above that supplied to satisfy exerted carbonaceous demand. Therefore, Equation 7, which described the relationship between rate of oxygen utilization and COD removal, must be modified as follows:

$$\frac{do}{dt} = \frac{d[COD]}{dt} + 3.43 \frac{[NH_4^+]}{dt} + 1.14 \frac{d[NO_2^-]}{dt} \qquad (8)$$

where $\frac{d[NH_4^+]}{dt}$ and $\frac{d[NO_2^-]}{dt}$ are respectively, the rates of oxidation of ammonia to nitrite and nitrite to nitrate.

Thus, one approach to achieve high nitrogen conservation is to obtain a high level of nitrification. This can be accomplished by providing sufficient oxygen for the aerobic system, adequate mixing, and a sufficient SRT. However, even with complete nitrification, total nitrogen conservation may not result since denitrification can occur. A number of facultative microorganisms will utilize nitrites and nitrates as terminal electron acceptors in place of molecular oxygen under anaerobic conditions. Although the actual reactions are complex, they can be summarized as follows:

$$2\ NO_3^- + 10\ H^+ \longrightarrow N_2 \uparrow + 4\ H_2O + 2\ OH^- \qquad (9)$$

$$2\ NO_2^- + 6\ H^+ \longrightarrow N_2 \uparrow + 2\ H_2O + 2\ OH^- \qquad (10)$$

The production of nitrogen oxides, $N_2O$ and/or NO, is possible. Analysis of gases from denitrification of aerated poultry wastewater indicated that $N_2$ is the major end product (30).

Although nitrifying organisms are autotrophic, denitrifiers are heterotrophic and require a source of organic carbon. In well stabilized effluents, addition of a source of organic carbon such as methanol is normally required. However, there is ample oxidizable organic carbon in poultry wastes and it does not appear that organic carbon will be the limiting substrate for denitrification in poultry wastewaters.

Another alternative to accomplish nitrogen conservation is to prevent nitrification and thus avoid subsequent denitrification and nitrogen loss.

A number of methods exist. One would be to exclude nitrifying organisms from the aeration system. Although these organisms are not present in fresh poultry wastes (30), they are widely distributed in the soil and can be easily introduced into aerobic treatment systems. Therefore, such exclusion would be impractical under commercial conditions.

A second method would be to reduce the system $\theta_c^m$ for nitrifying organisms. This is theoretically possible because both Nitrosomonas and Nitrobacter have slow growth rates in comparison to heterotrophic organisms associated with waste stabilization. A $\theta_c$ of less than three days at 20°C would be required (31). At this and shorter SRT values, waste stabilization would be minimal and the effectiveness of aerobic stabilization diminished.

A third and possibly the most practical approach is to limit oxygen availability. Nitrifying bacteria cannot compete with heterotrophic organisms for oxygen. Therefore, limiting oxygen input to that required to satisfy the exerted carbonaceous oxygen demand will prevent nitrification. Nitrogen losses can still occur via ammonia stripping. Prediction of these losses is possible although difficult due to the variables involved such as ammonia concentration, pH, temperature, and degree of turbulence.

Biological nitrification-denitrification is a feasible approach for nitrogen control with poultry wastes (4,11,30). This approach is attractive due to its compatibility with aerobic treatment for odor control. The only difference is that conditions to control nitrification and denitrification also are provided.

## OXYGEN TRANSFER

In an aerobic system, the oxygen transferred should be equal or greater than the biological oxygen requirements of the system. The oxygenation capacity of aeration equipment is normally determined in tap water at a zero dissolved oxygen concentration. However, equipment oxygenation capacity can vary under process conditions.

Oxygenation under process conditions can be described as:

$$N = \alpha K_L a(\beta C_s - C_L)\ (W)\ (10^{-6}) \tag{11}$$

where $N$ = oxygenation capacity, pound-time$^{-1}$
$K_L a$ = overall gas transfer coefficient, time$^{-1}$
$\alpha$ = the ratio of $K_L a$ in wastewater to $K_L a$ in tap water
$C_s$ = oxygen saturation concentration, mass/volume
$\beta$ = the ratio of $C_s$ in wastewater to $C_s$ in tap water
$C_L$ = the equilibrium dissolved oxygen concentration, mass/volume
$W$ = weight of liquid under aeration, pounds

The values of $K_L a$ and $W$ are functions of the aeration unit and system volume, and are constant for a given operating condition. $C_s$ is an independent variable related to liquid temperature and atmospheric pressure. Both $\alpha$ and $\beta$ are dependent variables. Although $\alpha$ is a function of many factors, it appears that it is primarily related to mixed liquor characteristics as is $\beta$ (32). $C_L$ is a function of the relationship between the quantity of oxygen supply and demand. The quantity of oxygen transferred is directly related to $\alpha$. Thus factors that affect $\alpha$ directly affect the oxygen transferred under process conditions.

Constituents of the mixed liquor under aeration can affect the quantity of oxygen that is transferred. Small quantities of surface active agents can cause significant reductions in $\alpha$ values (33-35). Downing (34) found that suspended solids in the range of 1,000 to 6,000 mg/ℓ have had little effect on oxygen transfer. However, $\alpha$ was reported reduced to 0.2 in a sludge with a total solids concentration of 10,000 mg/ℓ (36).

Alpha values in aerated poultry wastes have been shown to be related to mixed liquor total solids concentrations (6,37). The results indicated that $\alpha$ has the value of 1.0 at mixed liquor total solids concentrations less than 20,000 mg/ℓ. As total solids concentrations increase beyond that point, $\alpha$ values decrease to 0.4 at 55,000 mg/ℓ. This relationship between $\alpha$ and mixed liquor total solids concentration is presented in Figure 2.

The oxygenation capacity is also a function of $\beta$ (Equation 11). An empirical relationship describing the effect of salinity on $C_s$ has been developed (38) and may be used with reasonable accuracy for determination of $\beta$ in wastewater (39). Beta values in the range of 0.9 to 1.0 have been reported in studies involving domestic wastewaters (40-42). In aerated poultry manure slurries, $\beta$ appeared independent of total solids concentrations (42). Beta values approached unity for total solids concentrations up to 30,000 mg/ℓ.

The value of $C_L$ is important in that as N increases above that necessary to provide a minimum dissolved oxygen concentration, $C_L$ will increase. The result will be the decrease of the oxygen deficit, $C_s$-$C_L$. This in turn will reduce the oxygen transfer efficiency of the aerator and increase operating costs. In an aeration system, $C_L$ need be no more than that necessary for odor control, generally no more than 0.5 to 1.0 mg/ℓ, or for nitrification, generally about 2.0 mg/ℓ.

The combined effects of $\alpha$ expressed as total solids concentration and $C_L$ on required tap water aeration capacity for poultry wastewater is shown in Figure 3. The consequence of increasing oxygenation capacity is translated into higher capital and operating costs.

The relationships of SRT to degree of waste stabilization, and mixed liquor total solids concentration to oxygen transfer described previously, form a rational basis for the design and operation of aeration systems for poultry wastes. These concepts were employed in the design of the Manorcrest oxidation ditches and will be used in discussing and interpreting the results of this study.

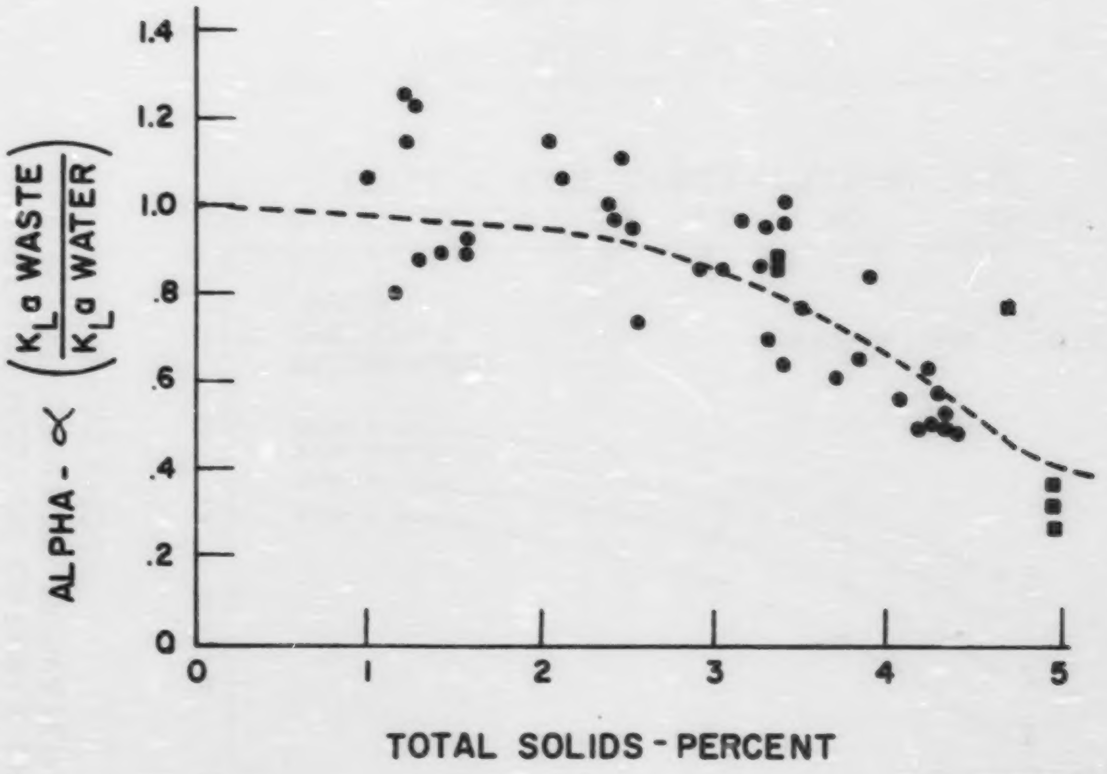


Figure 2. Relationship between α and mixed liquor total solids concentration in aerated poultry wastes (37)

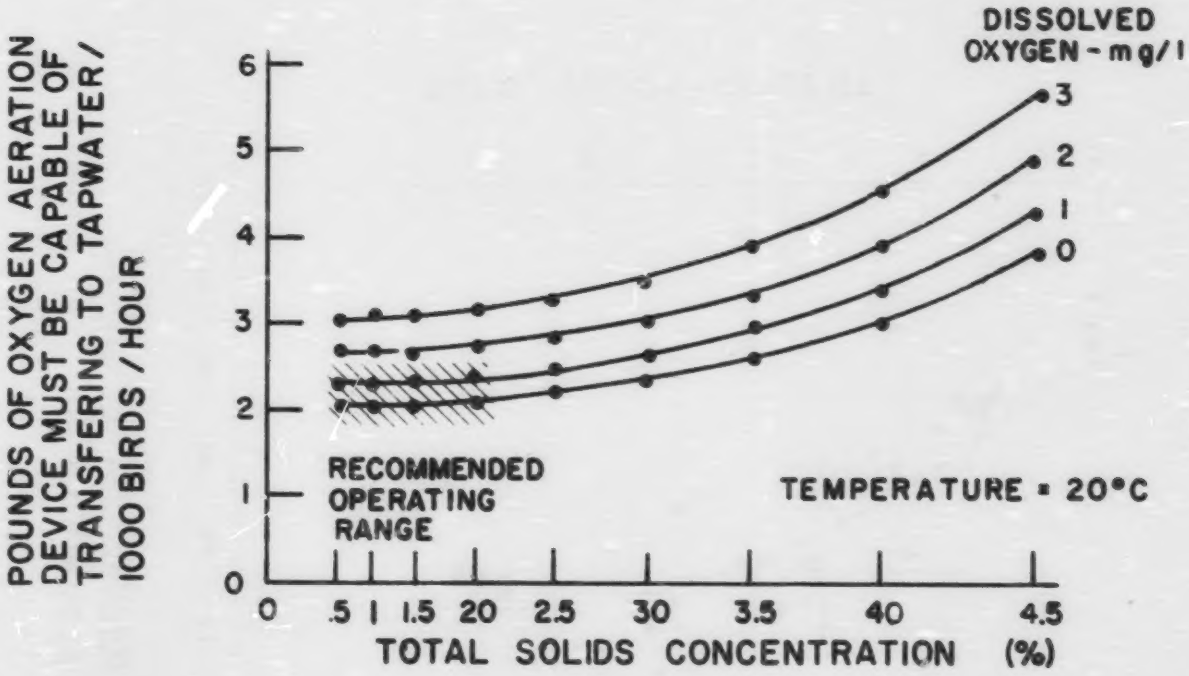


Figure 3. Aeration requirements in relation to mixed liquor total solids and $C_L$ (37)

## SECTION IV

## INVESTIGATIVE FACILITIES, SYSTEM DESIGN AND CONSTRUCTION

### INVESTIGATIVE FACILITIES

This study was conducted at Manorcrest Farms No. 2 which is located in Camillus, New York, less than 10 miles west of the city of Syracuse. This area (1975) is located in the outer fringe of the suburban Syracuse area. Details of the area are presented in Figure 4.

Manorcrest Farms are owned and operated as a family partnership. The farming activities consist of dairy and poultry enterprises accompanied by crop production to provide animal feed. The main farm is the site of the dairy operation. Farm No. 2 is the location of two-thirds of the poultry enterprise with cropping activities occurring on both farms.

The poultry operation is managed by Mr. Earl Hudson, one of the partners in Manorcrest Farms. He also served as grant director of this project. This enterprise is an integrated operation. Home grown grains are used in the manufacture of the poultry feed. The eggs produced are processed and packaged by Manorcrest Farms. The major portion of the egg production is sold at the wholesale level to retail food stores and institutions. The remainder is sold at a retail outlet on the farm.

Building No. 1 (Figure 4) was the site of the demonstration activities. The building is a single story poultry house with a capacity of 8,000 birds contained in four rows of stair-step cages. Figures 5 and 6 are a plan and cross-section of this building. Prior to the installation of the aeration systems, manure accumulated in 73 cm (29 in) deep pits and was removed semi-annually. Anaerobic conditions prevailed in these collection pits resulting in the production of malodors. These odors were discharged through ventilation fans and during manure spreading resulted in neighbor complaints. In addition, a fly problem existed during the warm months of the year.

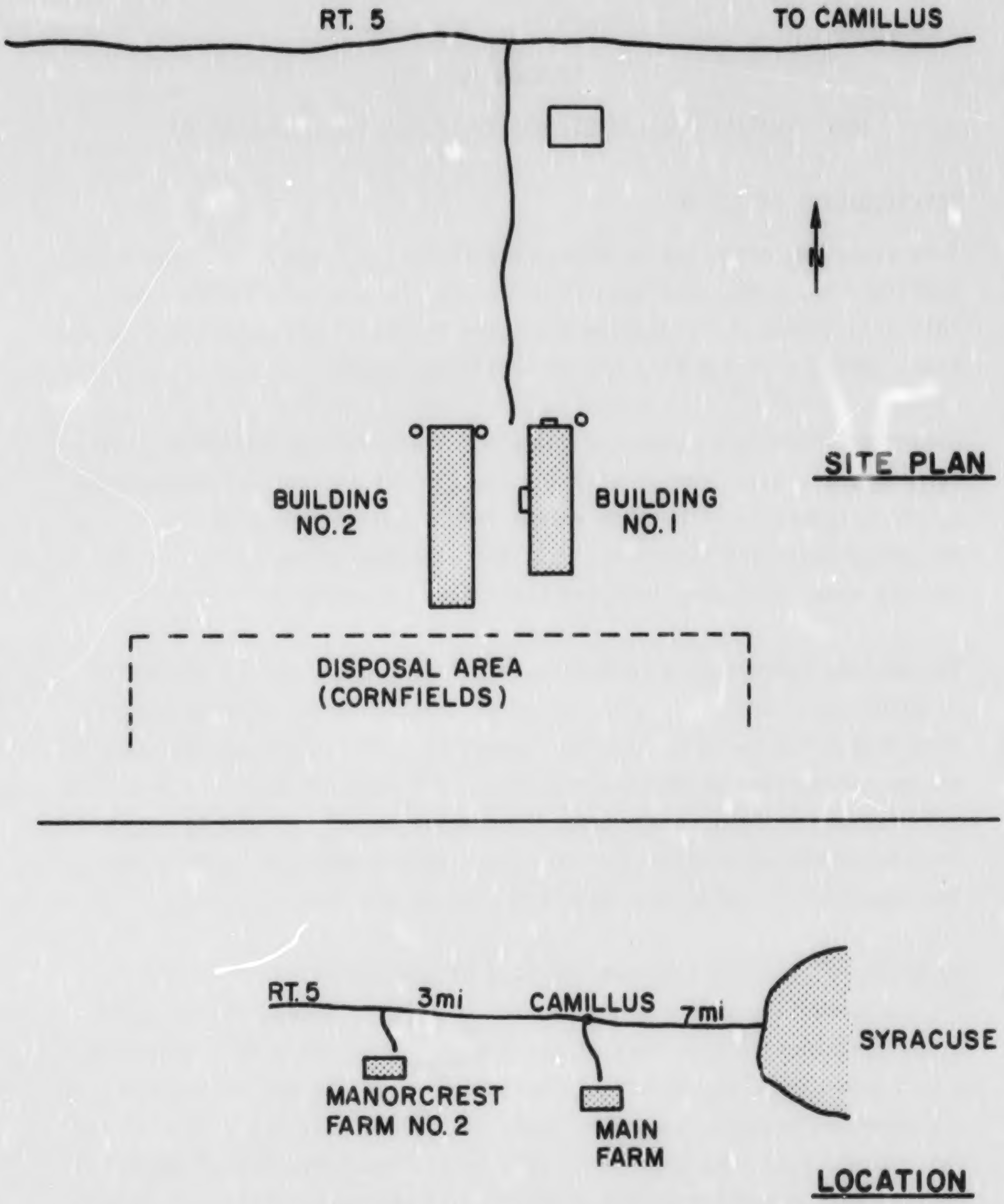

RT. 5
TO CAMILLUS
N
SITE PLAN
BUILDING NO. 2
BUILDING NO. 1
DISPOSAL AREA (CORNFIELDS)
RT. 5
3mi
CAMILLUS
7mi
SYRACUSE
MANORCREST FARM NO. 2
MAIN FARM
LOCATION

Figure 4. Location and site plan of Manorcrest Farm No. 2

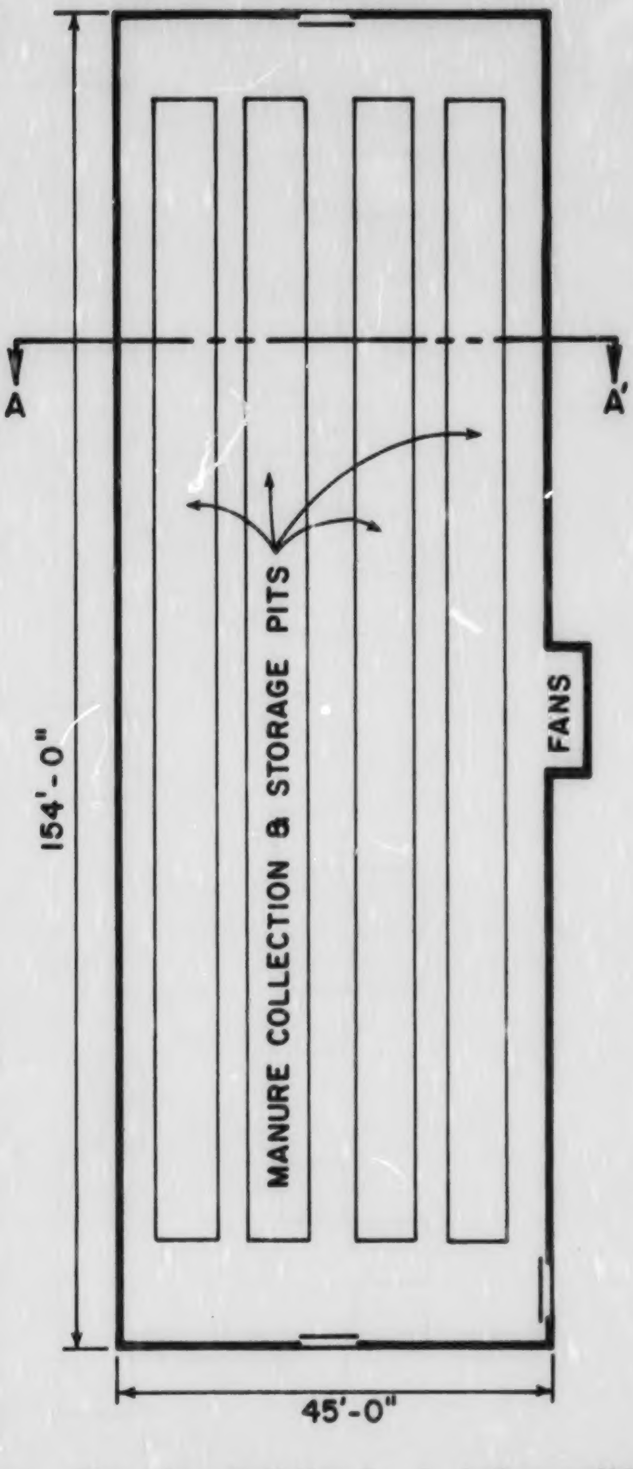

A
A'
154'-0"
MANURE COLLECTION & STORAGE PITS
FANS
45'-0"

Figure 5. Plan view, Building No. 1, before modification

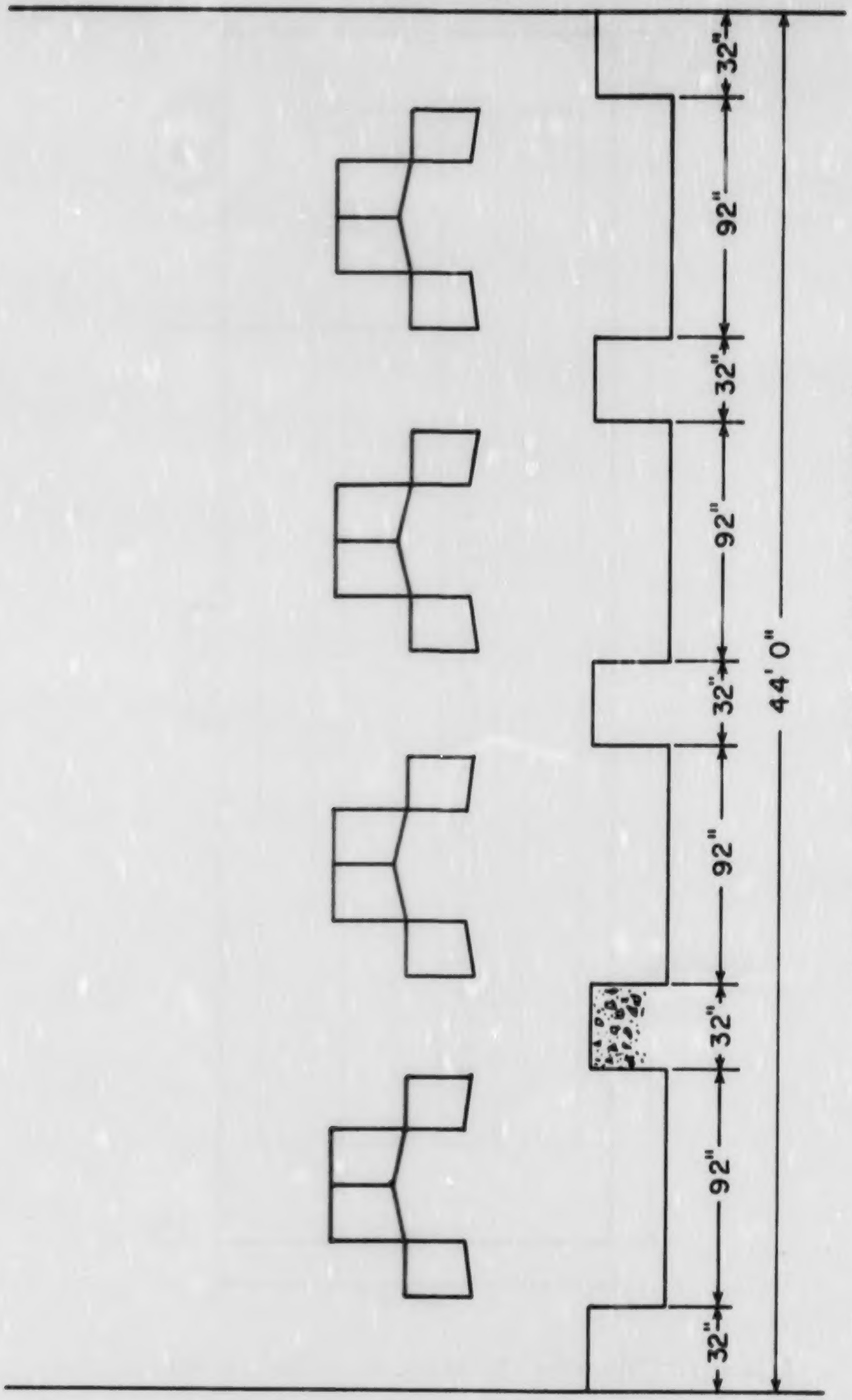

32"
92"
32"
92"
32"
92"
32"
92"
32"
44'0"

Figure 6. Cross section, A-A', Building No. 1

The other building, Building No. 2, is a two-story, high-rise poultry house with a capacity of 11,000 birds. The birds are located on the second floor. The first floor serves as a manure collection and storage area. Ventilation air is circulated over the wastes to promote drying. This building was not directly involved in the study except as a control to compare conditions and manpower associated with other poultry production and waste management situations.

Mr. Earl Hudson was responsible for the supervision of the construction activities in converting the existing waste management facilities in Building No. 1 to the aeration systems. In keeping with the concept of demonstration under commercial conditions, he was also responsible for the operation of both oxidation ditches including maintenance and ultimate disposal functions. General operating procedures were provided by Cornell University personnel.

Personnel from the Agricultural Waste Management Program, New York State College of Agriculture and Life Sciences at Cornell University acted as consultants to the project. Their responsibilities included systems design, provision of guidelines for operation, and evaluation of performance including identification of problem areas. Cornell personnel collected and analyzed the data necessary for performance evaluation.

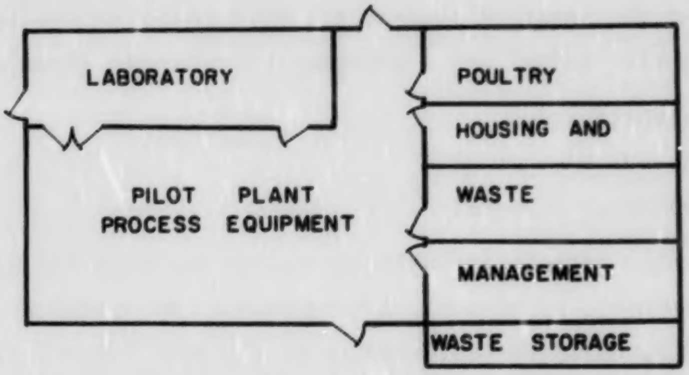
Also participating in the project were Professor Charles E. Ostrander, Extension Specialist in Poultry Science, Cornell University and Mr. Antonio Aja, Cooperative Extension Agent, Onondaga County, New York. These individuals assisted in the transfer of the project results to the poultry industry.

The oxidation ditches at Manorcrest were monitored for an 18 month period in order to collect necessary data to evaluate their performance. Cornell personnel visited the demonstration site at least twice a week to observe the systems, to make adjustments in operating procedures when necessary, and to obtain samples.

The Agricultural Waste Management Laboratory (AWML) at Cornell University served as a support facility for this investigation. The laboratory was constructed with funds from EPA Project 14040 DDG and contains a wet chemical laboratory, pilot plant process equipment, and animal housing facilities. Figure 7 is a floor plan of the Laboratory and illustrates the area used for sample analysis. Cornell personnel associated with the project were located at the AWML. Analyses of Manorcrest samples as well as supplemental studies were conducted in this facility.

The Manorcrest demonstration site was visited by numerous individuals during the course of the study. Visitors included representatives of the U.S. Environmental Protection Agency, the New York State Environmental Facilities Corporation, consulting engineers, and agriculturalists. Included in this latter group were members of the Cooperative Extension County Executive Committee of Onondaga County, New York, as well as several egg producers. The site was also inspected by foreign researchers and graduate students in the Agricultural Waste Management Program, Cornell University. In addition, the Manorcrest study was the subject of an article in the June 1974 issue of the "American Agriculturalist" which is a popular farm magazine. These activities were in keeping with the objective of the demonstration of aeration systems for poultry wastes.

A portion of the results of this investigation was presented at the International Symposium on Livestock Wastes - 1975 at the University of Illinois, Urbana - Champaign. The paper "An Evaluation of Aeration Systems for Poultry Wastes Under Commercial Conditions" was published in the proceedings of that conference. A second paper, "The Oxidation Ditch - Problems and Reasons" discussing the problem areas identified in this study will be presented at the American Society of Agricultural Engineers 1976 Summer Meeting at Lincoln, Nebraska. The results of this study have also been utilized by other members of the Cornell Agricultural Waste Management Program in the preparation of scientific papers, reports, and theses.


LABORATORY
POULTRY
HOUSING AND
WASTE
MANAGEMENT
PILOT PLANT
PROCESS EQUIPMENT
WASTE STORAGE

FLOOR PLAN

ANALYTICAL LABORATORY

Figure 7. Floor plan and analytical laboratory in the Cornell Agricultural Waste Management Laboratory

## SYSTEM DESIGN

### General

In the design of the aeration systems for this study, it was recognized that a comprehensive animal waste management system has three components.

1) stabilization
2) solids management
3) ultimate disposal

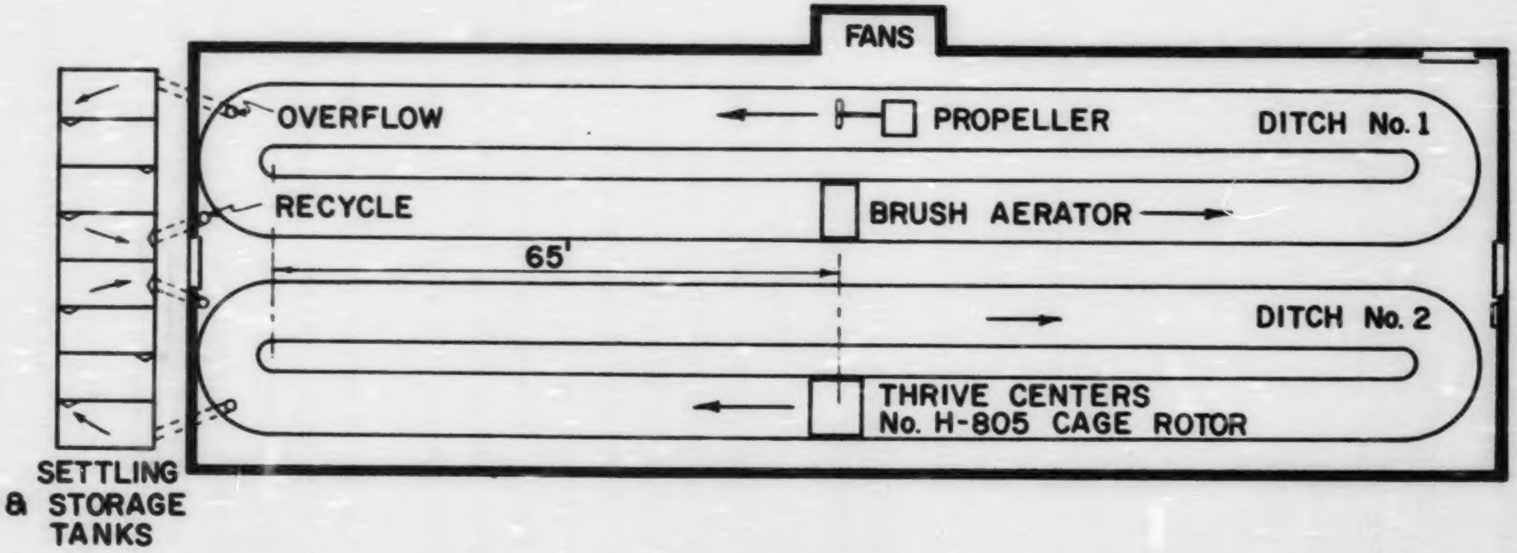
A number of aerated systems including an oxidation ditch and an aerated lagoon were considered as possible alternatives. An oxidation ditch inside the poultry buildings appeared to be the most logical alternative for the following reasons:

1) ease of incorporation in confinement housing
2) cold weather operational problems are eliminated
3) uniform loading directly from birds
4) equipment to move raw waste to the aerated unit is not required

In addition, it was possible to easily convert the existing manure collection pits to oxidation ditches.

The four existing collection pits, Figures 5 and 6, were converted into two oxidation ditches as shown in Figure 8. The only construction required was the connection of each pair of ditches with semi-circular channels at each end. Each ditch served approximately four thousand birds.

For design purposes, it was assumed that total solids production would be 40 gms/bird-days. This value is comparable to the value of 37 gms/bird-day reported elsewhere (16) and was conservative. Maximum total solids destruction was assumed to be 50 percent (Table 2). Other waste characteristics which were assumed are presented in Table 5 and are based upon reported characteristics (16).



FANS
OVERFLOW
PROPELLER
DITCH No. 1
RECYCLE
BRUSH AERATOR
65'
DITCH No. 2
THRIVE CENTERS
No. H-805 CAGE ROTOR
SETTLING
& STORAGE
TANKS

Figure 8. Plan view of oxidation ditches and settling tanks

Table 5. ASSUMED FRESH POULTRY MANURE CHARACTERISTICS

| Parameter | Gms/bird-day |
|---|---|
| Volatile solids | 29.7 |
| Fixed solids | 10.3 |
| TKN | 3.4 |
| COD | 31.1 |
| $BOD_5$ | 8.1 |

## Stabilization

Two different modes of oxidation ditch operation were considered:

1) continuously loaded, batch
2) steady-state with a constant SRT

The continuously loaded, batch method of operation has the advantage of combining stabilization and storage. This is probably the most common method of agricultural oxidation ditch management. With this approach the ditch would be emptied periodically, refilled with tap water, and the system restarted. Based upon a maximum mixed liquor total solids concentration of 50,000 mg/ℓ, maximum storage time for each ditch was calculated to be 73 days. The average SRT would be 26.5 days. If the total solids production rate were 30 gm T.S./bird-day, which also has been reported (10), the storage time would be 97 days.

The batch method of operation has advantages in simplicity of operation and combination of storage with treatment. However, there are several disadvantages. The primary liability is a low oxygenation efficiency at the high total solids concentrations that ultimately result with a batch system. An $\alpha$ value of 0.5 at a mixed liquor total solids concentration of 50,000 mg/ℓ has been reported (37). To maintain aerobic conditions, the required oxygenation capacity would be approximately twice the oxygen demand. This would result in increased capital and operating costs.

Other possible disadvantages to the batch mode of operation are:

1) potential of recurring "start-up" problems such as foaming and an initial imbalance in the food to microorganism ratio.
2) high, short term water requirements to refill the system.
3) additional energy requirements for mixing due to increasing viscosity at higher total solids concentrations.

It was possible that pumping and not oxygenation capacity would be the limiting criteria in sizing required aeration equipment for such a mode.

An alternative to the batch approach is a steady-state process with control of mixed liquor total solids concentrations via continual residual solids removal. This would allow maintenance of total solids concentrations of less than 20,000 mg/ℓ, thereby maximizing oxygenation efficiency. With this type of system, SRT would be a design and operating parameter. This would allow flexibility in matching degree of stabilization with overall waste management objectives.

Due to the potential advantages of maximizing oxygenation efficiency, the Manorcrest oxidation ditches were designed to operate at low mixed liquor total solids concentrations, and SRT was used as a basic design parameter.

The selection of the design SRT was based upon the objective of providing conditions which would permit nitrification. Since both Nitrosomonas and Nitrobacter are known to have slower growth rates than the heterotrophic organisms utilizing carbonaceous materials, calculation of the minimum system SRT ($\theta_c^m$) was based on nitrification. Information about Building No. 1 indicated that the average minimum temperature should not be below 10°C. Therefore, the value of 10°C was assumed as the minimum mixed liquor temperature.

The kinetic coefficients for nitrification at 20°C (44) were used to calculate $\theta_c^m$. A modified form of the van't Hoff-Arehenius relationship, Equation 12, was assumed adequate to correct the 20°C value of the maximum rate of substrate utilization per unit weight of microorganisms, K, to 10°C. The corrected K in turn was used to determine $\theta_c^m$ at 10°C.

$$K_{T_2} = K_{T_1} \cdot \theta^{(T_2-T_1)} \qquad (12)$$

where $\theta = 1.106$
$T$ = temperature °K

The $\theta$ value of 1.106 is that reported (44) for nitrification in the temperature range of 5 - 20°C. $\theta_c^m$ was calculated by using Equation 13 (27).

$$\theta_c^m = (YK-b)^{-1} \qquad (13)$$

The kinetic coefficients and $\theta_c^m$ at 20°C and the calculated $\theta_c^m$ at 10°C are noted in Table 6. The calculated $\theta_c^m$ values of 2.1 and 2.9 days for ammonia and nitrite oxidation at 20°C compare favorably with the two day $\theta_c^m$ for nitrification of poultry wastes reported elsewhere (4).

Based upon these calculations, a design SRT of 20 days was chosen to provide a safety factor of two for nitrification during winter operations. In order to simplify the design and prediction of parameter removals, it was assumed that SRT would be constant throughout the year. The expected performance at this design SRT was estimated from relationships of parameter removal and SRT that occurred in other poultry waste stabilization studies (12). The expected performance is presented in Table 7.

The anticipated solids destruction and resultant solids concentration were used to calculate the required volume for each ditch. A volume of 105,980 ℓ (28,000 gal) was calculated to have an equilibrium total solids concentration of 19,777 mg/ℓ at a 20 day SRT. This value is slightly below the 20,000 mg/ℓ which is the upper limit for best oxygenation efficiency. This volume resulted in a depth of 50.8 cm (20 in) in each Manorcrest ditch with a freeboard of 20.8 cm (8 in).

Table 6. KINETIC COEFFICIENTS AND $\theta_c^m$ FOR BIOLOGICAL NITRIFICATION USED FOR PROJECT OXIDATION DITCH DESIGN

| Process | Y, mg/mg N | b, $days^{-1}$ | K, mg N/mg-day | T°C | $\theta_c^m$, days |
|---|---|---|---|---|---|
| $NH_4$-N | 0.29 | 0.05 | 1.8 | 20 | 2.1 |
| Oxidation | 0.29 | 0.05 | 0.7 | 10 | 6.5 |
| $NO_2$-N | 0.084 | 0.05 | 4.7 | 20 | 2.9 |
| Oxidation | 0.084 | 0.05 | 11.7 | 10 | 10.7 |

Table 7. EXPECTED TREATMENT EFFICIENCIES OF AEROBIC POULTRY WASTES STABILIZATION AT A 20 DAY SRT

| Parameter | % Removal |
|---|---|
| Total Solids | 33 |
| Volatile Solids | 46 |
| COD | 36 |
| Organic Nitrogen | 62 |

The design volume was compared to the parameter of 0.5 kg $BOD_5/m^3$-day (0.03 lbs $BOD_5 ft^3$-day) suggested as adequate for oxidation ditch design (21). A $BOD_5$/T.S. ratio of 0.20 for poultry manure was assumed (Table 5). The design volume of 105,989 ℓ (106 $m^3$) had an expected volumetric loading rate of 0.3 kg $BOD_5/m^3$-day. Thus adequate performance was expected.

Oxygen requirements to satisfy carbonaceous and nitrogenous oxygen demand were determined utilizing Equation 8. It was assumed that one unit mass of COD removed represented one unit mass of carbonaceous oxygen demand that was satisfied. Based upon the assumed waste characteristics presented in Table 5 and the anticipated removals, Table 7, the daily COD removal for each ditch was calculated to be 44.78 kg/day and therefore the oxygen requirement for carbonaceous oxygen demand was assumed to be 44.78 kg/day. The anticipated nitrogenous oxygen demand was an additional 38.20 kg $O_2$/day. The anticipated oxygen requirements for the two levels of treatment, odor control and odor control plus nitrification, per 1000 bird-hrs, were:

Table 8. DESIGN ESTIMATES OF OXYGEN REQUIREMENTS

| Degree of Treatment | Gms $O_2$/1000 bird-hr |
|---|---|
| Odor control | 470 |
| Odor control & Nitrification | 860 |

The value of 860 gms $O_2$/1000 bird-hrs compared favorably with the oxygen requirement of 940 gms $O_2$/1000 bird-hrs determined from oxygen uptake rate measurements reported by Baker et al. (37), for an oxidation ditch treating poultry manure. The design value of 860 gms $O_2$/1000 bird-hrs is conservative when compared to the 2 x $BOD_5$ value of 670 gms $O_2$/1000 bird-hrs that has been suggested (21).

Solids Management

In order to maintain an equilibrium mixed liquor total solids concentration and SRT, removal of solids was required. The following options were considered:

1) creation of a continuous flow system by water addition
2) liquid-solids separation via gravitational settling

The first option was not considered practical due to the volume of effluent involved. To maintain a 20 day SRT, 5299 ℓ (1400 gal) of mixed liquor would have to be removed from each ditch daily. This would require the handling of 484 ℓ (128 gal) of wastewater per bird per year. A 1,290,667 ℓ (340,995 gal) lagoon would be required to provide three months storage of mixed liquor discharged for both oxidation ditches with this option.

Limited experience at the AWML indicated that liquid-solids separation via gravitational settling could be a feasible method of controlling mixed liquor total solids concentrations. However, detailed knowledge of aerated poultry waste settling characteristics was not available. An apparently conservative value of 50 percent solids removal via settling was assumed for design purposes. Based on expected biological removal of total solids, (Table 7), it was calculated that daily removal of 107 kg dry weight of total solids was necessary to maintain the desired equilibrium conditions. The required daily flow through the settling basin for each ditch was calculated to be 10,720 ℓ/day (2832 gal/day).

The design of the settling basins was based upon a number of factors. First, it appeared desirable to combine settling with sludge thickening and storage to simplify operation. Therefore, volume as well as surface area was an important design consideration. Limitation of funds in part constrained the maximum tankage volume that could be obtained. The lowest cost option in terms of cost per unit volume was 2500 gallons (9462 ℓ) precast concrete tanks. The design specified four tanks per oxidation ditch. The four tanks for each ditch had a surface area of 5m$^2$ (54 ft$^2$).

The arrows in Figure 8, indicate the direction of flow through the tanks. The method of operation was to withdraw clarified liquid from the last tank and reintroduce it into the ditch. This created an overflow of mixed liquor through a standpipe into the first settling tank.

Based upon required mixed liquor flow and settling tank volume, the design hydraulic detention time was 3.5 days. The calculated overflow rate was 2163 ℓ/day/$m^2$ (53 gal./day/$ft^2$). An overflow rate of 48,975 ℓ/day/$m^2$ (1200 gal./day/$ft^2$) for poorly settling activated sludge has been suggested as adequate (24). Therefore, it appeared that sufficient settling capacity was available with flexibility for increasing overflow rates if necessary.

The amount of storage time provided, and the volume of material requiring ultimate disposal, was a function of the degree of sludge thickening. Anticipated values for sludge volume on a daily basis and storage time are given in Table 9.

Table 9. DESIGN VALUES FOR SLUDGE STORAGE TIME

| Sludge Concentration (mg/ℓ) | Volume of Sludge per day (ℓ) | Storage Time (days) |
|---|---|---|
| 40,000 | 2684 | 14.1 |
| 50,000 | 2150 | 17.6 |
| 60,000 | 1785 | 21.2 |
| 70,000 | 1532 | 24.7 |

## Ultimate Disposal

The 60.7 ha (150 acres) of crop land located adjacent to the poultry houses (Figure 4) has served as the site of ultimate disposal for the wastes produced on this farm. The available land is used for continuous corn production. The corn crop is harvested as grain which is field shelled. Production averages 63 kg/ha (100 bu/acre).

The ability of the available land to accept the wastes produced by the 19,000 birds located on this farm was estimated as part of the overall project design. The objective was to determine the level of stabilization which would be required to prevent adverse environmental impact from ultimate disposal of these wastes. Both total solids and nitrogen loadings were considered. Based upon the assumed waste production values (Table 5), the yearly total solids production was calculated to be 277,400 kg (611,013 lbs). This would result in an application rate of 4570 kg/ha/yr (4073 lbs/acre/yr). This value is substantially below the level of 101 metric tons/ha/yr (45 tons/acre/yr) which has been demonstrated to be acceptable (2).

The total nitrogen production per year was calculated to be 23,371 kg/yr (51,478 lbs/yr). This would result in an application rate of 385 kg N/ha/yr (343 lbs N/acre/yr). At the maximum recommended application rate for corn of 224 kg N/ha/yr (4), it was calculated that 42 percent of the nitrogen excreted by the birds on this farm should be removed prior to land application to avoid potential nitrogen problems.

The consideration of some nitrogen loss by denitrification and hence the inclusion of nitrification as a process design objective was based upon this fact. It was assumed that denitrification would occur during settling and sludge storage and perhaps also in the ditches.

## CONSTRUCTION

The four existing collection pits (Figures 5 and 6), were converted to two oxidation ditches by the removal of the end walls in each pit followed by construction of four semicircular channels. The result was the formation of two elongated loops. The outer perimeter of each semicircular channel was formed with precast concrete silo staves. The inner surface of the outer perimeter was plastered with mortar to seal the joints between the staves. A concrete floor was poured in each semicircular channel.

The connecting channels extended beyond the ends of the cage rows into the service alleys. To permit movement of feed and egg carts as well as personnel, it was necessary to cover the semicircular channels. Pressure treated wood was used for beams and joists. Exterior grade plywood was used as flooring.

Four interconnected 9462 ℓ (2500 gal) precast concrete tanks provided settling and sludge storage facilities for each oxidation ditch. The tanks were located outside the poultry house (Figure 8). The tanks were interconnected and connected to the oxidation ditches with 20 cm (8 in) bituminous fiber pipe. Influent pipes to each tank were baffled to minimize turbulence. Influent and effluent lines were alternated to minimize short circuiting of flow.

## EQUIPMENT SELECTION

Two different types of surface aeration equipment were employed, one in each oxidation ditch, to evaluate alternatives for aeration of oxidation ditches. One was a cage rotor which functioned as both an aeration and mixing device. The second aeration unit was a brush type rotor. Design of the latter aerator was based on oxygenation and appeared to require a supplemental mixing unit. A submerged industrial propeller was used to provide supplemental mixing. Equipment placement is shown in Figure 8.

Although several commercial cage rotors were available, a Thrive Centers, Inc. unit was selected. This choice was based in part on availability of operating characteristics as well as familiarity with a similar cage rotor at the AWML. The channel width of 2.3 m (7.7 ft) limited the maximum length of a single cage rotor to 1.68 m (5.5 ft). The rotor, model H-805, had a diameter of 70 cm (27.5 in) and was driven by a 3.7 kw (5 hp) motor at a speed of 100 rev/min. The maximum recommended immersion depth for this unit is 15.2 cm (6 in.).

The oxygenation characteristics of the Thrive unit were not available from the manufacturer. However, characteristics presented by Jones, et al. (45) and unpublished test data (46) were available. These studies involved rotors of the same design at a 15.2 cm (6 in) immersion depth and resulted in the data in Table 10.

Table 10. OXYGENATION CAPACITY FOR THE THRIVE CENTER CAGE ROTOR

| Rotor Length cm (in) | Oxygenation Capacity gms $O_2$/m/hr (lbs $O_2$/ft/hr) | Reference |
|---|---|---|
| 55.9 (22) | 2150 (1.4) | (46) |
| 66.0 (26) | 2383 (1.6) | (45) |
| 114.3 (45) | 1974 (1.3) | (45) |

The results are approximately equal. Therefore, a value of 2150 gms $O_2$/m/hr was used for design purposes for the expected rotor size. It was estimated that the 1.68 m rotor would transfer 3612 gms $O_2$/hr. This amount was greater than the maximum anticipated oxygen demand of 3440 gms $O_2$/hr thereby providing a small safety factor. The ability of the 1.68 m rotor length to provide adequate mixing was estimated as follows. A minimum oxidation ditch velocity not less than 0.38 m/sec (1.25 ft/sec) has been suggested (21) to provide adequate mixing. The pumping capacity of the Thrive Centers cage rotor was reported (47) to be 29.3 ℓ/sec/m rotor length (3.4 $ft^3$/sec/ft rotor length). It was calculated that a 1.68 m rotor should provide a velocity of 0.44 m/sec (1.46 ft/sec) and it appeared that the 1.68 m cage rotor was adequate in both mixing and oxygenation capacity.

The brush type rotor manufactured by Montair, Inc. was of a new design. It differed from conventional brush rotors in two ways. First, round bars were used in place of flat blades to reduce resistance when creating turbulence for oxygen transfer. Second, in place of multiple rows of blades, this unit had only two rows of round bars positioned to form a double spiral. With this geometry only two bars strike the liquid surface at a given instant. This reduced the impact load on the aerator power transmission components. The unit sized to fit the 2.3 m (7.7 ft) Manorcrest channel width had a rotor length of 2.1 m (6.8 ft). It was driven by a 1.5 kw (2 hp) gearhead motor. Rotor speed was varied by changing sprocket sizes. Maximum immersion depth was 15.2 cm (6 in).

The operating characteristics of this unit, i.e., oxygen transfer and pumping capacity, were not known. However, it appeared that this aerator had the potential for greater oxygen transfer efficiency expressed as gms $O_2$ per kwhr. Another apparent advantage was the light weight of the aerator which would facilitate maintenance and repair when necessary. Since the pumping capacity of this aerator was questionable, supplemental pumping was provided by a 38.4 cm (15.1 in) industrial propeller driven by a 2.2 kw (3 hp) variable speed motor. The propeller had a design pumping capacity of 15,500 ℓ/min (4095 gal/min) at the maximum speed of 350 rpm. It was estimated that the propeller would provide a supplementary liquid velocity of 0.2 m/sec (0.7 ft/sec) at a 50.8 cm (20 in) liquid depth. This combination of the brush aerator and propeller was installed in Ditch I while the cage rotor was used in Ditch II. Two small 0.4 kw (0.5 hp) helical screw pumps were specified to recycle settling tank effluent.

# SECTION V

# METHODS AND MATERIALS

## OXYGEN TRANSFER

The oxygen transfer capacity of both aeration units in tap water was determined at the outset of the evaluation phase of the study. The tests were conducted between the completion of construction and equipment installation and the initial operation of the ditches as treatment units. The non-steady state chemical method (39) was used. Sodium sulfite ($Na_2SO_3$) in the presence of a catalyst, cobalt chloride ($CoCl_2$), was used to deplete the dissolved oxygen concentration. The cobalt chloride was added to achieve a concentration of 0.2 mg/ℓ in the tap water in each ditch. Both chemicals were dissolved prior to addition. Manual mixing was employed in an effort to achieve uniform chemical distribution.

Following the commencement of aeration, the rate of increase of the dissolved oxygen concentration was measured with YSI model 54 dissolved oxygen meter. The meter was standardized against saturated distilled water at a known temperature and atmospheric pressure. Saturated oxygen concentrations were obtained from Standard Methods (48). The temperature of the tap water was measured at the time of these tests.

The oxygen transfer coefficient, $K_La$, was computed using the following equation:

$$\frac{dc}{dt} = K_La(C_s - C_t) \qquad (14)$$

where $\frac{dc}{dt}$ = change in dissolved oxygen concentration with time

$K_La$ = overall oxygen transfer coefficient, $time^{-1}$

$C_s$ = oxygen saturation concentration, mass/volume

$C_t$ = dissolved oxygen concentration at time t, mass/volume

$K_La$ was determined from semi-logarithmic plots of the oxygen deficit, $C_s$-$C_t$, versus time. A least squares exponential regression program was used to fit a straight line to the experimental data and calculate the slope of the line, $K_La$.

The values of $C_s$ were obtained from Standard Methods (48) and corrected using local barometric pressure readings obtained from the U.S. Weather Bureau, Hancock Field, Syracuse, New York. Hancock Field is located approximately twenty miles from the demonstration site and is at the same elevation. The following equation was used to calculate the actual value of $C_s$.

$$C_s \text{ (actual)} = [C_s \text{ (tabular value)}] \frac{\text{Local Atmos. Pressure (in Hg.)}}{\text{29.92 in Hg.}} \qquad (15)$$

All $K_La$ values were corrected to 20°C using the following relationship.

$$K_La_T = K_La_{20°C}(\theta)^{(T-20)} \qquad (16)$$

where $K_La_T$ = value of $K_La$ at T°C

$K_La_{20°C}$ = value of $K_La$ at 20°C

$\theta$ = temperature correction factor, 1.02

Equation 11, (Section III), was used to calculate the mass of oxygen transferred per unit time.

VELOCITY MEASUREMENTS

The velocity of tap water in each oxidation ditch was measured with a Gurley model number 622 current meter. This was a direct acting current meter. Velocity measurements were made at two locations in each ditch as indicated in Figure 9. To determine the average velocity in each cross-section, measurements were made at the locations indicated in Figure 10. The results were averaged vertically and then horizontally to obtain the average velocity at each location.

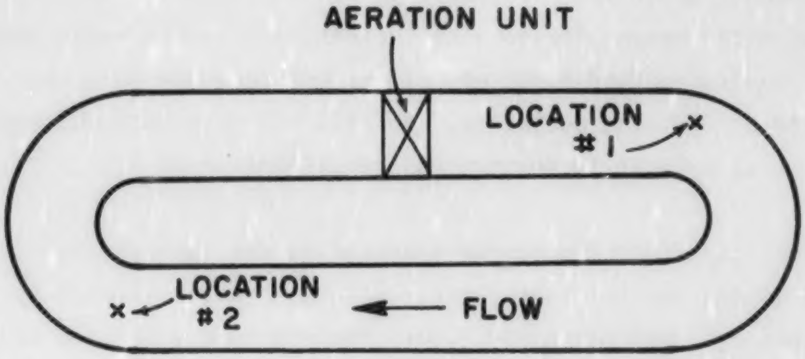

AERATION UNIT
LOCATION #1
LOCATION #2
FLOW

Figure 9. Location of velocity measurements, plan view

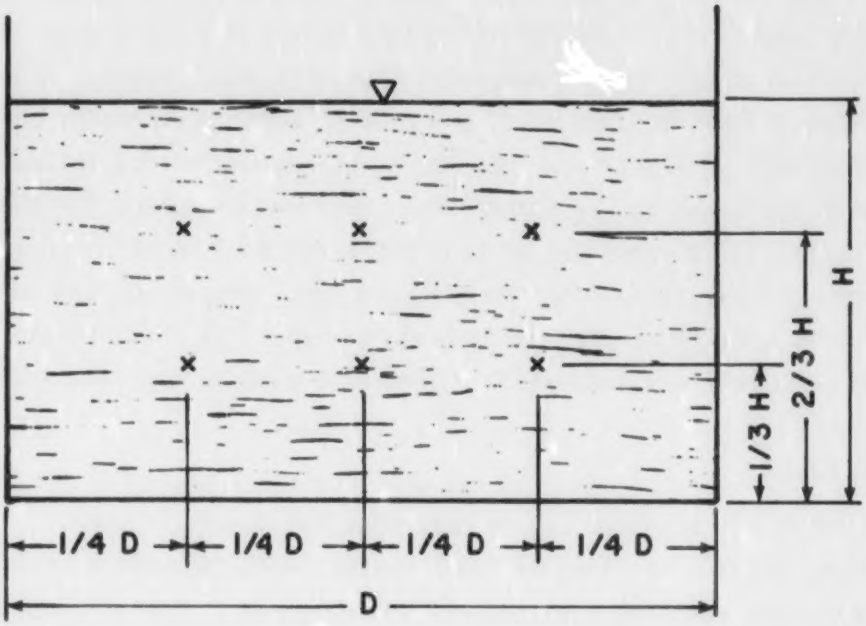

1/4 D
1/4 D
1/4 D
1/4 D
D
H
2/3 H
1/3 H

Figure 10. Location of velocity measurements, cross section

Attempts were made to measure ditch velocity under process conditions. Both the current meter and a subsurface float were used. The cups on the current meter became fouled with feathers which eliminated this approach. The subsurface float was also unreliable due to cross-currents and accumulated sediments. No reliable data were obtained with respect to velocity under process conditions.

One important aspect of the oxygen transfer studies was to compare the efficiency of the two aeration systems. This normally is done by measuring energy consumption and expressing efficiency as mass of oxygen transferred per unit energy consumed. However, electric motor efficiency increases as loading approaches the design maximum. For a given motor, the ratio of power consumed to power produced will be less at lower than design loadings.

In order to eliminate this variable and thus provide an equal basis for comparison, the shaft power was determined for each motor under the various test conditions. This was accomplished by measuring energy consumption of each motor with commercial type watt-hour meters. These data were then translated into shaft power using motor performance curves. Performance curves were obtained from the manufacturers of the motors supplied with the brush and cage aerators. Performance curves for the propeller drive, which consisted of a variable speed DC motor and gear reducer, were not available from the manufacturer. Therefore, dynamometer tests were performed to develop performance curves. The performance curves that were used are presented in Figures 1 through 4 of the appendix.

## DATA COLLECTION

To perform materials balances and to determine the degree of waste stabilization, routine sampling of fresh wastes, oxidation ditch mixed liquor (ODML), and settling tank supernatant returned to the ditches was conducted through the course of the study. A 24 hour, composite sample of raw manure was collected weekly from randomly selected groups of four hens. The raw manure was collected by suspending a tray below an individual cage. Grab samples of ODML and return supernatant were taken twice a week. All samples were returned to the AWML and analyzed on the day of collection.

The raw waste samples were analyzed for the following parameters:

Total manure production per bird-day
Total solids
Volatile solids
Chemical oxygen demend (COD) - total and soluble
Total Kjeldahl nitrogen (TKN)

The mixed liquor and settling tank supernatant were analyzed for the following:

Total solids
Volatile solids
COD - total and soluble
TKN
Ammonia nitrogen ($NH_4$-N)
Nitrite nitrogen ($NO_2$-N)
Nitrate nitrogen ($NO_3$-N)
pH
Temperature
Dissolved oxygen (D.O.) - mixed liquor only

## ANALYTICAL METHODS

Total and volatile solids were determined as described in Standard Methods (48). TKN was determined by a micro-Kjeldahl method (49). Ammonia nitrogen was determined using the stream distillation procedure (50). Nitrite-nitrogen was determined by diazotization (51). Nitrate-nitrogen was described by a salicylic acid method (50). The rapid method (52) was used to measure COD. Soluble COD was defined as that portion of the total COD that would pass through a 0.8 μ millipore filter. The presence of nitrifying organisms, Nitrosomonas and Nitrobacter, was determined using a procedure for estimation of active nitrifying organism concentrations (53). Dissolved oxygen concentration and temperature of the mixed liquor were measured in the ditches at the time of sampling with a YSI, model 54 oxygen meter. Dissolved oxygen concentrations were measured at the locations indicated in Figure 8 to provide a profile of dissolved oxygen concentration in relation to distance from the aeration unit. The oxygen uptake rate was determined by aerating a mixed liquor sample and then measuring the decrease of dissolved oxygen with time.

Zone settling velocity was determined by measuring the downward movement of a sample mixed liquor-supernatant interface with time. The tests were conducted in a 1 $\ell$ graduated cylinder. Samples were not stirred.

## CALCULATION OF SRT AND TREATMENT EFFICIENCY

The conventional approach to calculation of SRT is based upon the following relationship.

$$\text{SRT} = \frac{\text{wt. of solids in the system}}{\text{wt. of solids leaving the system/time}} \qquad (5)$$

It is implied in this method of calculation that all of the solids leaving the system are lost in the effluent, and that they can be measured. However, in the Manorcrest oxidation ditches, solids were removed from the system in two ways. One method of removal was by the intentional settling of mixed liquor. The other was via uncontrollable sedimentation in the ditches. Although it was possible to measure the solids lost through the settling tanks, accurate determination of solids lost via sedimentation was not possible.

The problem of sedimentation required a different approach to the calculation of SRT. Although suspended solids are commonly used in the calculation of SRT, use of total, volatile, or fixed solids is also valid. In any given system, constant relationships should exist between these types of solids. At equilibrium, the fixed solids entering the system should equal those leaving the system assuming fixed solids generated or lost during treatment are minimal. This permitted a different approach to the calculation of SRT. It was possible to accurately determine the quantity of fixed solids entering the system. By assuming the quantities of fixed solids entering the system were equal to those leaving the system by any physical means, it was possible to estimate SRT as follows:

$$\text{SRT} = \frac{\text{wt. of fixed solids in the system}}{\text{wt. of fixed solids entering the system/unit time}} \qquad (17)$$

This was the approach used to determine SRT in this study. Mixed liquor fixed solids concentrations were used to determine when equilibrium conditions were attained.

Equation 18 defines treatment efficiency in terms of influent and effluent waste characteristics.

$$E = \frac{S_0 - S_1}{S_0}(100) \qquad (18)$$

where $E$ = treatment efficiency, percent

$S_0$ = influent waste characteristic

$S_1$ = effluent waste characteristic

In a completely mixed system, the mixed liquor and effluent should have the same characteristics and either concentration can be used. This equation can be used in several ways. The most common is to express $S_0$ and $S_1$ as concentrations, mass per unit volume. A second approach is a total mass balance with $S_0$ and $S_1$ representing total mass in and out of the treatment system. A third method is based on the ratio of any given parameter such as total and volatile solids, organic nitrogen and COD to a constant factor such as fixed solids in both raw and stabilized waste. The latter was the approach used for the calculation of treatment efficiencies in this study.

The following is an example of this method of calculation of treatment efficiency. Ratios of a given parameter to fixed solids in the raw wastes and mixed liquor were calculated from analyses to determine concentration per unit volume of both the parameter and fixed solids in each sample. The fixed solids ratio was then calculated as follows:

$$\begin{array}{c}\text{Fixed solids ratio,}\\ \text{mass/mass}\end{array} = \frac{\begin{array}{c}\text{Concentration of parameter,}\\ \text{mass/volume}\end{array}}{\begin{array}{c}\text{Concentration of fixed solids}\\ \text{mass/volume}\end{array}} \qquad (19)$$

The ratio calculated from raw manure analyses represented $S_0$ in Equation 18 while $S_1$ was the ratio calculated from results of mixed liquor analyses. The difference between $S_0$ and $S_1$ represents biological removal from the system.

Either the first or third method could have been used to estimate treatment efficiency. The inability to accurately determine losses via sedimentation eliminated the total mass balance approach. The fixed solid ratio approach was selected because it was similar to the means of SRT estimation in that both are based on fixed solids. This approach provided a simple and rapid method of monitoring system performance.

## ECONOMICS

Capital costs, building modifications and equipment were amortized at an interest rate of 9 percent to determine annual costs. Time periods used are as follows:

| | |
|---|---|
| Structures | 20 years |
| Aeration Equipment | 10 years |

Energy consumption was continually measured for each electric motor in order to determine energy costs. Where operating conditions resulted in motor loadings that were below values which produced peak motor efficiency, corrections in measured energy consumption were made to determine energy consumption at peak motor efficiency. This was done when operating conditions were such that the electric motor was significantly underloaded and could have been replaced with a smaller size motor. The motor performance curves (Appendix, Figures 1 through 4) were used for this purpose. The measured input energy was used to determine energy output. This value was then used to calculate energy consumption at the peak motor efficiency for that motor as indicated in the performance curves. The variable speed D.C. motor for the propeller drive had a low peak efficiency, 62 percent, in comparison to an A.C. motor. Since a variable speed D.C. motor normally would not be used, the value of 70 percent, which is realistic for an A.C. motor, was used in the case of the propeller. The electrical energy cost to Manorcrest Farms throughout the study remained constant at $0.0201 per kilowatt hour. This included the fuel adjustment charge as well as the base rate.

# SECTION VI

# SYSTEM PERFORMANCE RESULTS

## INTRODUCTION

The project "Demonstration of Aeration Systems for Poultry Wastes" covered the period from March 1973 through June 1975. Details of the major phases of the study are contained in Table 11.

Table 11. AN OUTLINE OF THE MANORCREST DEMONSTRATION ACTIVITIES

| Time Period | Activities |
|---|---|
| March - May 1973 | System design and equipment selection and acquisition |
| June - August 1973 | Construction, electrical work and equipment installation |
| August 1973 | Oxygen transfer studies |
| September 1973 - March 1975 | System operation for demonstration and evaluation |
| March - June 1975 | Detailed analyses of data; preparation of final report |

It was necessary to integrate the construction activities and the oxygen transfer studies with the replacement schedule for the chickens located in Building No. 1. This resulted in the extended period for design and construction.

The initial operating conditions for each oxidation ditch are presented in Table 12.

Table 12. SUMMARY OF INITIAL OPERATING CONDITIONS, SEPTEMBER 1973

| | Ditch I | Ditch II |
|---|---|---|
| Bird number | 4,000 | 4,000 |
| Volume | 105,980 ℓ<br>(28,000 gal) | 105,980 ℓ<br>(28,000 gal) |
| Liquid depth | 50.8 cm<br>(20 in) | 50.8 cm<br>(20.in) |
| Aeration unit | | |
| Speed | 252 rpm | 100 rpm |
| Immersion depth | 15.2 cm<br>(6 in) | 12.7 cm<br>(5 in) |
| Propeller speed | 232 rpm | -- |
| Oxygen transfer capacity | 1403 gms $O_2$/hr | 3360 gms $O_2$/hr |

Over the 19 months that the aeration systems were monitored, several changes in operating conditions were instituted. These changes are listed in Table 13. The aerator speed in Ditch I was increased to evaluate system performance at a higher level of oxygen transfer. The resulting increase in mixed liquor velocity due to increased pumping by the aerator made the propeller expendable. Since the propeller housing was impending foam movement and causing a significant sediment accumulation, it was removed. The reason for the reduction in liquid depth was to increase mixed liquor velocity to reduce sedimentation. This problem will be discussed in greater detail at a later point.

This section contains the experimental results of the study. Included are results of the oxygen transfer and velocity studies, system performance, system costs, and identification of problem areas.

Table 13. CHANGES IN OPERATING CONDITIONS

| Date | Change |
|---|---|
| 1/7/74 | Aerator speed in Ditch I increased to 310 rpm. Immersion depth decreased to 11.4 cm (4.5 in.). |
| 1/17/74 | Propeller in Ditch I was removed |
| 9/1/74 | Volume of each ditch reduced to 68,887 ℓ (18,200 gal.). New liquid depth was 33 cm (13 in.). |

## OXYGEN TRANSFER STUDIES

Oxygen transfer studies were conducted in both ditches following the completion of construction and equipment installation. The specific objectives of these studies were to:

1) establish baseline oxygen transfer data
2) evaluate the brush aerator-propeller combination as an alternative aeration approach

The scope of these studies was restricted by two factors. First, the cages were empty during construction and only a limited time period was available prior to the housing of new birds. Second, the flow rate of the farm water supply was limited. Therefore, it was necessary to purchase water to run these tests. Thus, only one filling of each ditch was possible. The results reported were limited to the data obtained from the first 10 trials, although 12 tests were conducted in each ditch. The data collected during the 11th and 12th trials were of poor quality. Accumulation of salts or other contaminants was the probable cause of this phenomenon. Problems resulting from poor mixing of the chemicals with the tap water and leakage in Ditch II reduced the usable data to that collected during 4 of the 12 trials.

## Ditch I

The aeration system in this ditch was the experimental brush aerator and the propeller mixer. The relationship of two variables, brush aerator speed and velocity of ditch contents, to oxygenation efficiency was examined in this ditch. The test conditions included two brush aerator speeds, 126 and 252 rpm at a constant immersion depth of 15.2 cm (6 in). Propeller speeds included 0, 115, and 232 rpm. Cavitation limited the maximum propeller speed to 232 rpm. Both oxygen transfer and velocity measurements are presented in Tables 14 and 15 respectively. Shaft power, kilowatts, or horsepower were obtained from energy consumption data and motor efficiency curves.

The results presented in Tables 14 and 15 show the relative impact of each device on both oxygenation and pumping efficiencies. The propeller did not perform any aeration. Increased propeller speed, and therefore ditch velocity, decreased the oxygenation efficiency per unit of power utilized. Peak pumping efficiency did not occur when the propeller was used alone. Although the data indicates that the propeller was more efficient than the brush aerator for pumping, the most effective situation was the combination of the 126 rpm aerator speed and the 115 rpm propeller speed. This combination also had the highest oxygenation efficiency, 1684 gms $O_2$ per kw-hr.

However, oxygen transfer was only 527 gms $O_2$ per hour or 132 gms $O_2$ per 1000 bird-hours for 4000 birds. This value was significantly below value for odor control of 470 gms $O_2$ per 1000 bird-hours (Table 8). Consequently, the combination of the 252 rpm aerator speed and the 232 rpm propeller speed which provided 351 gms $O_2$/1000 bird-hours was used for initial phase of Ditch I operation.

Table 14. RESULTS OF OXYGEN TRANSFER MEASUREMENTS - DITCH I

| Test Conditions, RPM | $K_La_{20}$ Min-1 | Gms $O_2$/ Hr. | Shaft Power, Watts | Gms $O_2$/ KwHr |
|---|---|---|---|---|
| Aerator - 252 | .024 | 1403 | .947 | 918 |
| Propeller - 232 | | | .582 | |
| Aerator - 252 | .024 | 1403 | .947 | 1482 |
| Propeller - 0 | | | 0 | |
| Aerator - 126 | .011 | 616 | .306 | 694 |
| Propeller - 232 | | | .582 | |
| Aerator - 126 | .009 | 527 | .306 | 1684 |
| Propeller - 115 | | | .700 | |
| Aerator - 0 | ≈ 0 | -- | .582 | -- |
| Propeller - 232 | | | | |

Ditch II

Rotor immersion depth was the variable examined in this oxygen transfer study of the cage rotor. Trials were conducted at two immersion depths, 7.3 and 12.7 cm (2.9 and 5 in.). The results of these trials are noted in Tables 16 and 17. The cage rotor had a greater oxygenation and pumping capacity than the system in Ditch I. However, both oxygenation and pumping efficiencies were lower. Therefore, higher operating costs per unit oxygen transferred could be expected for this system.

The results of cage rotor oxygen transfer measurements are compared to results of other studies in Figure 11. The other studies also involved Thrive Centers cage rotors of the same design as the Manorcrest unit. As shown in the Figure, there is good general agreement between the Manorcrest results and those of the other investigations. It appears

Table 15. RESULTS OF VELOCITY MEASUREMENTS - DITCH I

| Aerator Speed, RPM | Propeller Speed, RPM | Average Velocity,* m/sec | Pumping Capacity, ℓ/sec | Shaft Power, Watts | Efficiency ℓ/sec/watt-hr |
|---|---|---|---|---|---|
| 126 | 0 | 0.06 | 71 | 306 | .232 |
| 126 | 115 | 0.12 | 142 | 313 | .454 |
| 126 | 232 | 0.24 | 285 | 887 | .321 |
| 252 | 0 | 0.15 | 178 | 947 | .188 |
| 252 | 232 | 0.26 | 309 | 1529 | .202 |
| 0 | 232 | 0.11 | 130 | 582 | .223 |

*Average of velocities measured at locations 1 and 2 (Figure 9)

Table 16. RESULTS OF OXYGEN TRANSFER MEASUREMENTS - DITCH II

| Immersion Depth, cm (in.) | $K_La_{20}$, $min^{-1}$ | Gms $O_2$/hr | Gms $O_2$/meter of rotor length | Shaft Power, watts | Efficiency Gms $O_2$/KwHr |
|---|---|---|---|---|---|
| 7.3 (2.9) | 0.036 | 1925 | 1148 | 1678 | 1147 |
| 12.7 (5) | 0.062 | 3360 | 2005 | 2759 | 1218 |

Table 17. RESULTS OF VELOCITY MEASUREMENTS - DITCH II

| Immersion Depth, cm (in.) | Average Velocity, m/sec | Pumping Capacity ℓ/sec | Shaft Power, watts | Efficiency, ℓ/sec/watt |
|---|---|---|---|---|
| 12.7 (5) | 0.38 | 458 | 2759 | .166 |

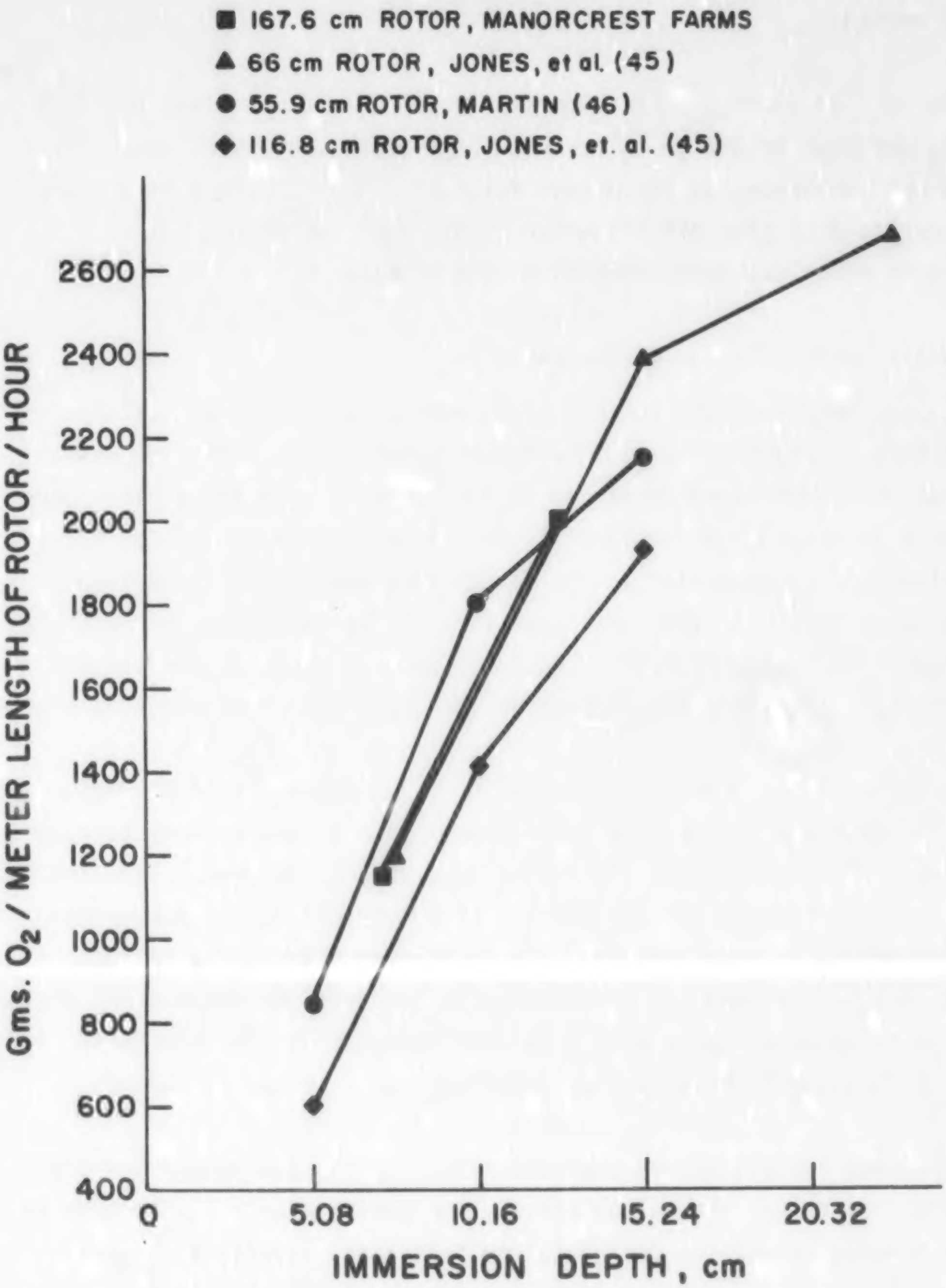


Figure 11. Comparison of oxygen transfer characteristics, Thrive Centers cage rotors

that the differences are due to factors such as ditch size and geometry which varied.

At the 12.7 cm (5 in.) rotor immersion depth, oxygen transfer was 3360 gms $O_2$ per hour or 840 gm $O_2$ per 1000 bird-hours for 4000 birds. This value was comparable to the design value of 860 gms $O_2$/1000 bird-hours for odor control plus nitrification (Table 8). Therefore, this immersion depth was used under operating conditions.

## RAW WASTE QUANTITIES AND CHARACTERISTICS

The laying hens involved in this study were a commercially available breed white leghorn chickens, the Shaver strain. The period of oxidation ditch operation exceeded one laying cycle. Since these birds were replaced at the end of the first cycle, 12 months, two groups of birds were involved in this study. The first group was housed in September 1973, concurrent with the start operation of the oxidation ditches, and the second in September 1974. The birds were 20 weeks of age and had started egg production when placed in the cages over the oxidation ditches.

There was no major change in the mass or characteristics of the manure with increasing bird age. Therefore, each year's results were averaged and are presented in Table 18. Only small changes in waste characteristics occurred between the two years. These variations could have been due to changes in feed. No feed analysis information was available, since most of the feed is manufactured on the farm from home grown grains. Noticeable changes were the 11.4 percent increase in COD and the 12 percent increase in fixed solid production per bird-day in 1974-75.

The observed quantities and characteristics of the raw manure are significantly lower than the values assumed for design (Table 5). Due to the lower loading rates, the design safety factor was greater than that originally estimated. Precise reasons for the difference in raw waste characteristics are unclear. Two factors are possible differences in

Table 18. RAW MANURE CHARACTERISTICS, MANORCREST FARMS

| | 1973-74 | 1974-75 |
|---|---|---|
| $\frac{\text{gms TS}}{\text{bird-day}}$ | 29.6 | 29.0 |
| $\frac{\text{gms VS}}{\text{bird-day}}$ | 22.1 | 20.6 |
| $\frac{\text{gms FS}}{\text{bird-day}}$ | 7.5 | 8.4 |
| $\% \frac{\text{VS}}{\text{TS}}$ | 74.8 | 72.0 |
| $\frac{\text{gms COD}}{\text{bird-day}}$ | 19.2 | 21.4 |
| $\frac{\text{gms TKN}}{\text{bird-day}}$ | 2.3 | 2.2 |
| $\frac{\text{gms BOD}_5}{\text{bird-day}}$ | 4.9 | -- |
| $\frac{\text{BOD}_5}{\text{COD}}$ | .26 | -- |
| % Soluble COD | 24.5 | 23.3 |
| $\frac{\text{mg COD}}{\text{gm FS}}$ | 2565 | 2544 |
| $\frac{\text{mg TKN}}{\text{gm FS}}$ | 307 | 263 |
| $\frac{\text{gms VS}}{\text{gms FS}}$ | 2.9 | 2.4 |

diet and the strain of bird. The values used for design were obtained from Babcock white leghorn chickens.

## SYSTEM PERFORMANCE

### Introduction

The rationale of using SRT as a design and operational parameter for slurry type biological treatment systems was discussed in Section III and used in the design of these aeration systems. In order to confirm or nullify the validity of this approach, system performance was evaluated at several different SRT's. In addition, the differences in oxygenation capacity of the two aeration systems (Table 12) provided comparison of two different levels of oxygen transfer. The increase of the brush aerator speed (Table 13) provided a third level of oxygen transfer. The relationships between quantity of oxygen supplied to both waste stabilization and nitrogen transformations were examined.

Physical design and mechanical difficulties limited the number, and in some cases, the length of equilibrium SRT conditions. Accumulation of sediments in both ditches was one serious problem. It was necessary to completely empty each ditch on two occasions. This will be discussed later in greater detail. Mechanical problems resulted in the stopping of the Thrive rotor for periods exceeding 24 hours on at least eight occasions. Operation of the brush aerator was also interrupted several times. These occurrences either interrupted equilibrium conditions or prolonged the time period necessary to reach steady-state.

### General

Throughout the course of the study, both aeration systems provided a high degree of odor control. This was true at all three levels of oxygenation and the various SRT's evaluated. At the lowest level of oxygen transfer, 351 gms $O_2$ per 1000 bird-hours, the odor of ammonia due to ammonia stripping was detectable in the immediate vicinity of the aeration unit. No waste associated odors were present in other areas of the building or in the ventilation exhaust air streams when continuous aeration was provided. Malodors did occur following restart of aeration units after mechanical problems. However, reestablishment of odor control was accomplished within approximately three to six hours depending on the length of aerator shutdown. The longest breakdown period was four days. No other vermin problems were observed.

The only point in these two systems where malodors were generated was in the settling and sludge storage tanks. Although odors were evident when sludge was being removed for ultimate disposal, the intensity was not of sufficient magnitude to create any problems during pumping or field spreading. In addition to door control, the presence of house flies, *Musca domestica*, which breed in animal manures, was essentially eliminated. There was no need to use any fly control measures through the course of the study.

## Relationship of SRT to Treatment Efficiency

To demonstrate and quantify the relationship between SRT and treatment efficiency with respect to aerated poultry wastes, treatment efficiencies at six different SRT's were determined. SRT was varied by controlling the rate of solids removal in the settling system. Precise selection of SRT was not possible due to problems in liquid-solids separation which will be discussed later. This accounts for the non-uniform distribution of SRT's which ranged from 10.5 to 36.5 days. However, it was possible to establish steady-state conditions at six different SRT's. Removals of total and volatile solids, COD, and organic nitrogen were calculated for each period.

Relationships between SRT and the percentage removal of each parameter are presented in Figures 12 and 13. These results show that as SRT increased, removal of each parameter also increased. Details of each equilibrium period are given in Table 1 of the Appendix.

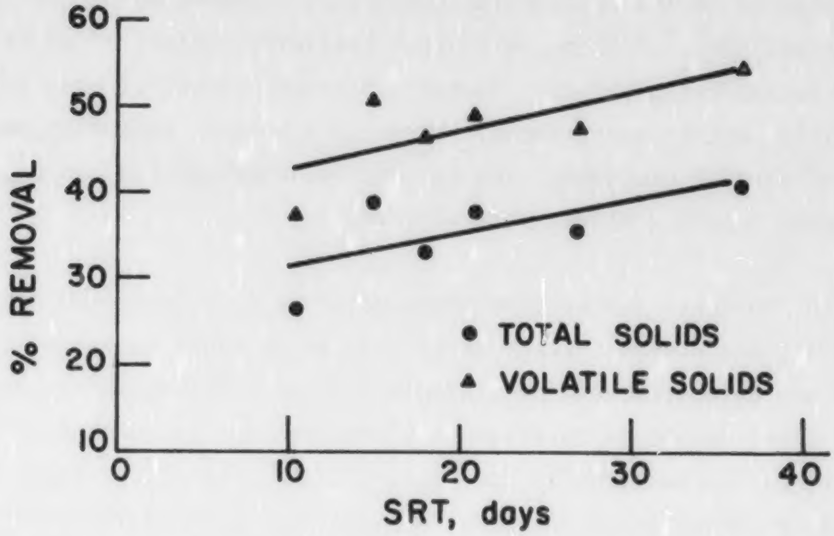


Figure 12. Observed relationships between SRT and removal of total and volatile solids

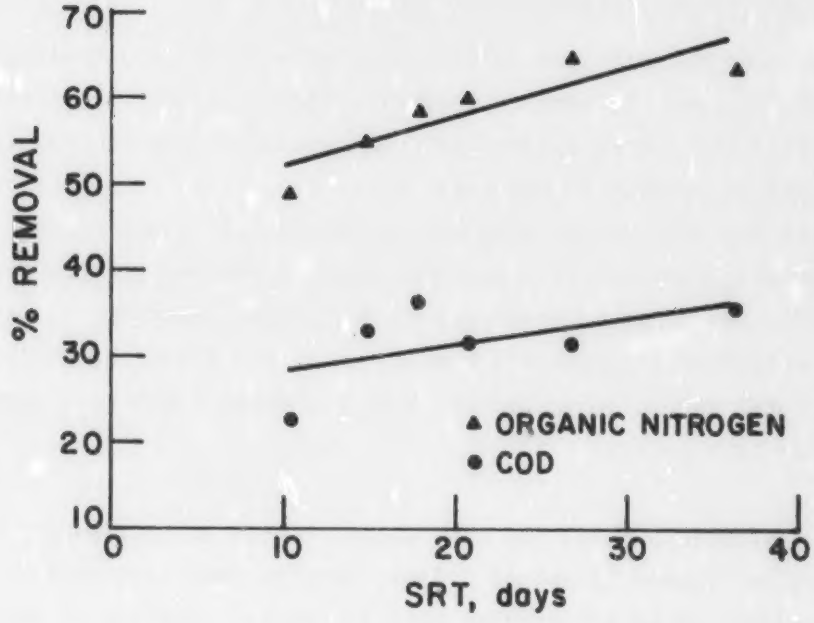


Figure 13. Observed relationships between SRT and removal of organic nitrogen and COD

## Relationship of Oxygen Supply to Process Performance

The Manorcrest oxidation ditches were operated at three different levels of oxygen transfer in order to develop a relationship between oxygen supply and process performance. The three levels were 350, 520, and 840 gms $O_2$ per 1000 bird-hours. For purposes of simplicity, these three levels of oxygen transfer capacity will be referred to as Levels I, II, and III. Due to the relationship of mixed liquor total solids concentrations to $\alpha$ (Figure 2), estimated oxygen transfer for the three SRT's at Level III were less than the tap water value of 840 gms $O_2$ per 1000 bird-hours. This was not due to any changes in system operation. These Levels were examined concurrently with SRT in order to correlate oxygen input with treatment efficiency.

The absence of malodors indicated that the exerted carbonaceous oxygen demand was satisfied aerobically even at the lowest level of oxygen input. Comparison of carbonaceous oxygen demand satisfied expressed as COD removed with the oxygen transferred under process conditions is presented in Table 19. Oxygen transferred under process conditions was calculated using the relationship between mixed liquor total solids concentrations and $\alpha$ presented earlier (Figure 2). The quantity of COD removed was based on the calculated treatment efficiency for each detention time.

The conclusion that the exerted carbonaceous oxygen demand was being satisfied as indicated by odor control is substantiated by these values. In all cases, the rate of oxygen transfer exceeded the rate of COD removal. These data indicate that treatment efficiency, i.e., total and volatile solids, COD, and organic nitrogen removal, was not limited at any time by the lack of available oxygen. The variations in the rates of COD removal appear to be related to changes in SRT.

Average dissolved oxygen concentrations (DO) for the range of conditions studied are given in Table 20. The designations 1/4 and 3/4 point

## Table 19. COMPARISON OF COD REMOVED WITH OXYGEN SUPPLY

| Level of Oxygen Transfer | SRT, Days | Total Solids Concentration, mg/ℓ | α Factor | Oxygen* Transferred gms/1000 bird-hr | gms COD Removed/** 1000 bird-hrs |
|---|---|---|---|---|---|
| I | 15 | 9,960 | 1 | 351 | 263 |
| II | 21 | 13,550 | 1 | 520 | 250 |
|  | 10.5 | 13,760 | 1 | 520 | 200 |
| III | 18 | 21,570 | 0.95 | 798 | 322 |
|  | 27 | 19,800 | 0.97 | 815 | 251 |
|  | 36.5 | 23,830 | 0.94 | 790 | 280 |

* Calculated oxygen transfer under process conditions
**Calculated from raw waste characteristics and removal results

Table 20. DISSOLVED OXYGEN CONCENTRATIONS

| Level of Oxygen transfer gms $O_2$/1000 bird-hrs | SRT Days | Average dissolved oxygen concentration, mg/ℓ | | Temp. °C |
|---|---|---|---|---|
| | | 1/4 Point | 3/4 Point | |
| 350 | 15 | 1.0<br>(0.7 - 1.55)* | 0.25<br>(0.1 - 0.4) | 13 |
| 520 | 21 | 1.0<br>(0.5 - 1.6) | 0.3<br>(0.1 - 0.5) | 12 |
| 520 | 10.5 | 1.1<br>(0.6 - 1.5) | 0.2<br>(0.2 - 0.3) | 13 |
| 798 | 18 | 1.5<br>(1.0 - 1.8) | 0.4<br>(0.3 - 0.6) | 16 |
| 815 | 27 | 4.5<br>(1.4 - 7.3) | 3.9<br>(0.4 - 6.9) | 13 |
| 790 | 36.5 | 2.6<br>(1.4 - 4.8) | 1.4<br>(0.4 - 3.2) | 13 |

*Range of values

indicate the distance downstream from the aeration unit at which the DO measurements were made (Figure 8). The relatively high DO levels at the 3/4 point for the 27 and 36.5 day SRT suggest that the DO of the mixed liquor entering the rotor may not have been zero. Therefore, the quantity of oxygen transferred would have been less than the values stated in Table 20. The calculated quantities of oxygen transferred were based upon a maximum oxygen deficit, $C_S - C_L$, where $C_L$ is zero. This indicates that the total oxygen demand, carbonaceous and nitrogenous, was less than the maximum potential oxygen supply from the aeration unit.

### Removal of Soluble COD

The removal of the soluble fraction of total COD in poultry wastes by aeration was examined at four different SRT's. As shown in Table 21, observed removals varied but always exceeded 85 percent. These data indicate that the major portion of soluble COD removal from poultry wastes in aeration systems will occur at SRT's of 10.5 days or less and corroborated the data shown in Table 2 and Figure 1.

Table 21. OBSERVED REMOVAL OF SOLUBLE COD

| Level of Oxygen Transfer | SRT, Days | Removal of Soluble COD, Percent |
|---|---|---|
| I | 15 | 86.8 |
| II | 10.5 | 93.8 |
|  | 21 | 95.7 |
| III | 27 | 92.5 |
|  | 36.5 | 90.4 |

## RESULTS

### Nitrogen

The systems design identified nitrogen removal as a necessary design objective for Manorcrest Farm No. 2. Two areas involving nitrogen removal were examined. The first concerned the determination of whether or not seeding is necessary to establish a population of nitrifying organisms. Included in this area were patterns of nitrification. The second was to compare nitrogen removal at different levels of oxygen transfer. Comparison included both method and extent of nitrogen removal.

### Seeding and Patterns of Nitrification -

Each oxidation ditch was thoroughly cleaned to remove any residue from previous manure accumulations before the oxygen transfer studies. Neither ditch was intentionally seeded with nitrifying organisms prior to commencement of operation under process conditions. In Ditch II, nitrification, as indicated by the presence of nitrites ($NO_2$-N), was first observed on the 14th day of operation (Figure 14). Sweeping of material on the building floors into both ditches during routine cleaning may have introduced the nitrifying organisms.

During the start-up period, days 0 through 74, Ditch II was operated as a continuously loaded, batch reactor to build the microbial population and to reach the desired mixed liquor total solids concentration. Mixed liquor concentrations of ammonia ($NH_4$-N), nitrite ($NO_2$-N), and nitrate ($NO_3$-N), plus pH for this time period are presented in Figure 14. Following the onset of nitrification, this period was characterized by high concentrations of $NO_2$-N in comparison to $NO_3$-N. Nitrification reduced the initial accumulation of $NH_4$-N, but $NH_4$-N concentrations increased slowly following the initial decrease.

Aeration was interrupted on days 74 through 76 due to aerator mechanical problems. Denitrification during this period reduced $NO_2$-N and $NO_3$-N concentrations. Following reestablishment of aerated conditions,

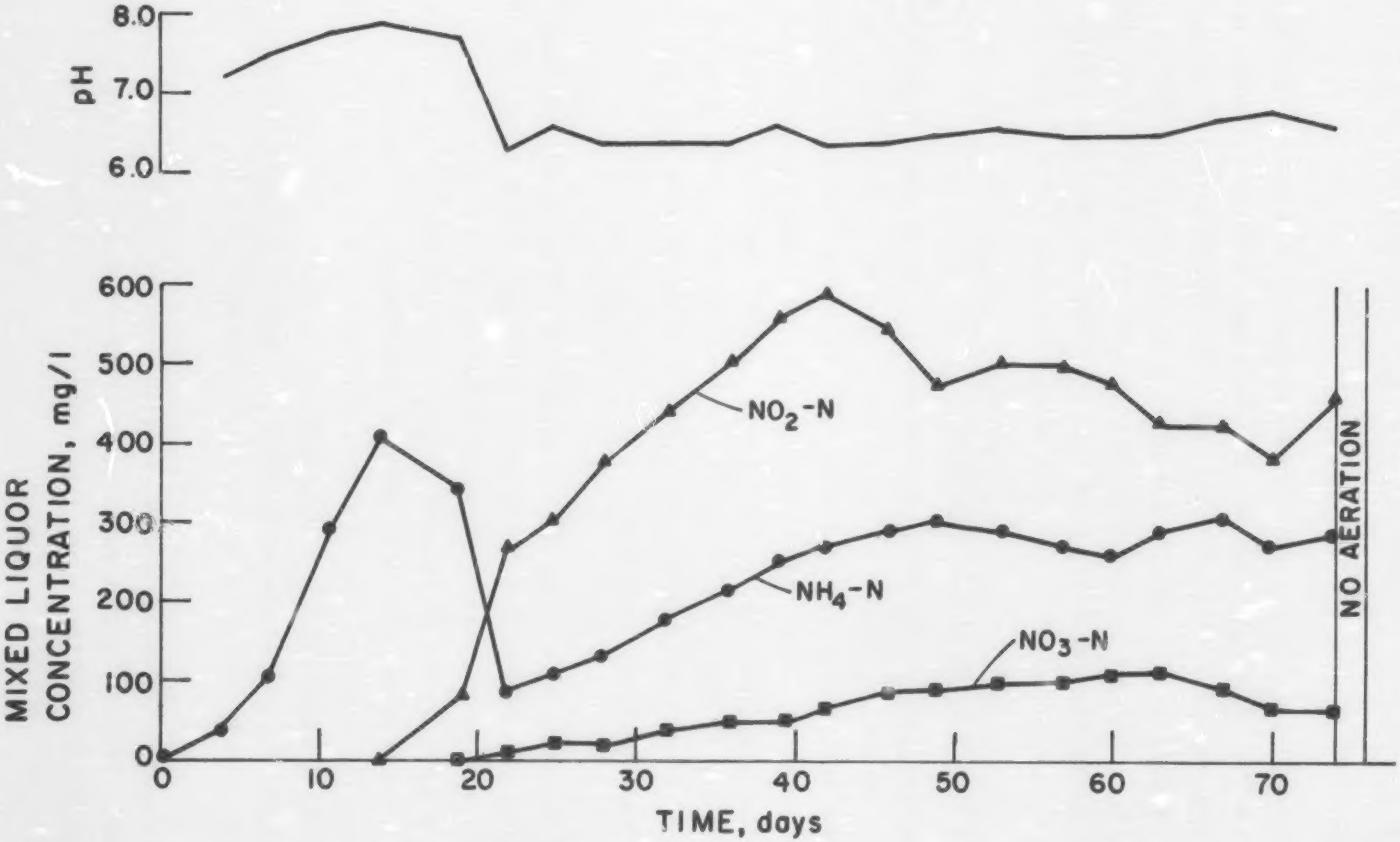


Figure 14. Nitrogen transformations during the start-up period, Ditch II

$NO_2$-N accumulation reoccurred (Figure 15). Solids removal to achieve equilibrium conditions started on day 81. Therefore, Ditch II was no longer a continuously loaded batch system. Aeration was again interrupted on two occasions as noted. Significant denitrification was not observed during or after either of these latter non-aerated periods.

Only data from two periods of nitrite accumulation are presented here. However, the same phenomenon was observed on several other occasions following aerator breakdowns and when Ditch II was restarted for the second year. Unfortunately, aeration could not be continuously maintained for a sufficiently long time period to determine if complete nitrification, accumulation of $NO_3$-N, would occur. Aerator mechanical problems were the cause for the frequent interruptions in aeration.

Nitrogen Removal

The removal of total nitrogen was examined in relation to the three levels of oxygen transfer previously described. Comparison of removal of total versus organic nitrogen and the details of operating conditions for four steady-state periods are presented in Table 22. Losses of total nitrogen ranged between 48.8 and 63.3 percent under the various conditions. Both ammonia desorption and nitrification-denitrification were observed as mechanisms of nitrogen removal. Desorption occurred at the lowest level of oxygen input with nitrification-denitrification occurring at the higher levels. The following sections contain the results obtained at each level of oxygen input.

a - Nitrogen removal at 351 gms $O_2$ per 1000 bird-hours - At this level of oxygen input, significant nitrification, as identified by measurements of $NO_2$-N or $NO_3$-N concentrations above trace levels, was not observed. Active mass determinations established that both Nitrosomonas and Nitrobacter were present although in low numbers. Insufficient oxygen, as evidenced by low mixed liquor dissolved oxygen concentrations (Figure 16) and not

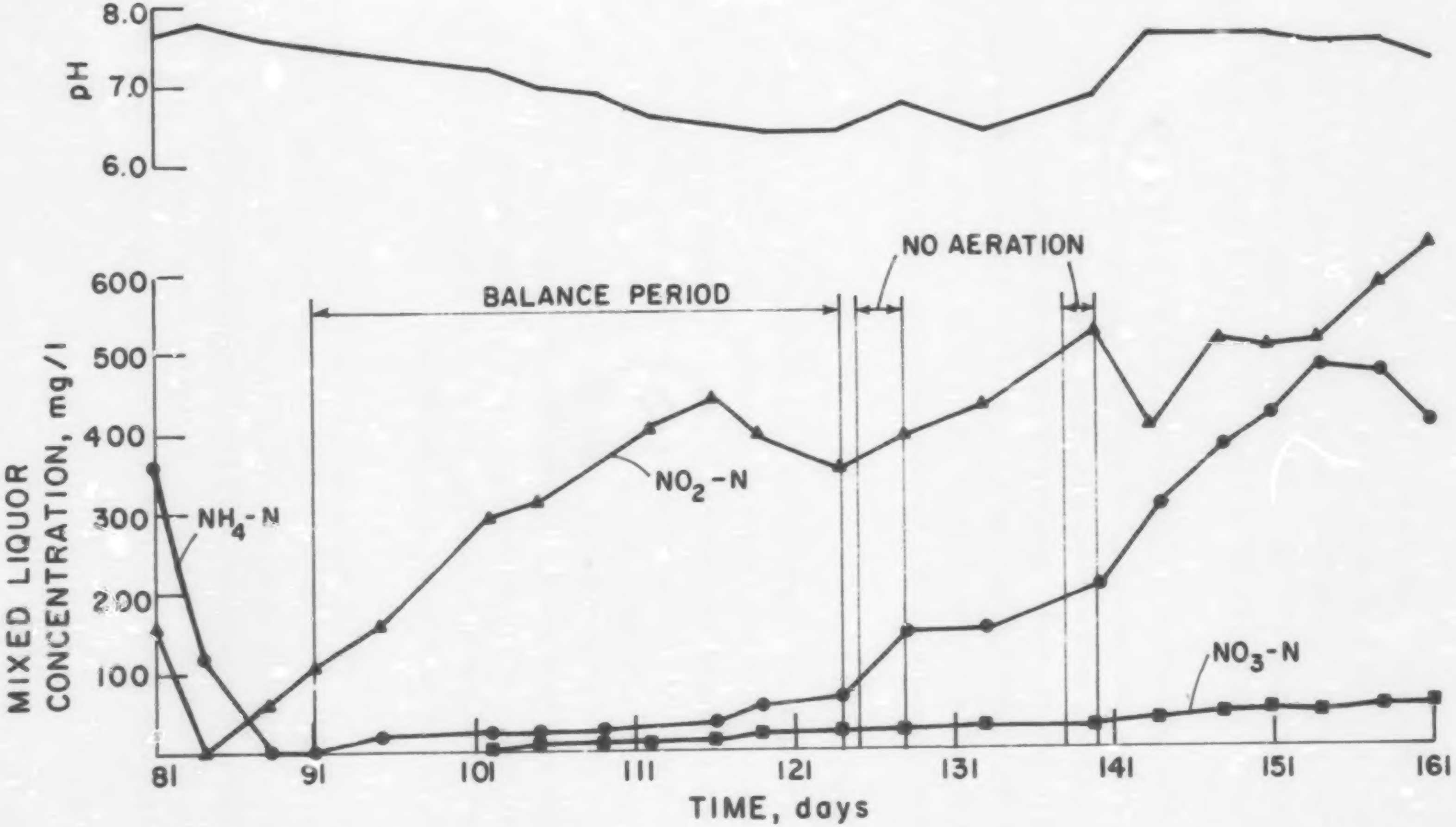


Figure 15. Reoccurrence of nitrite accumulation in Ditch II

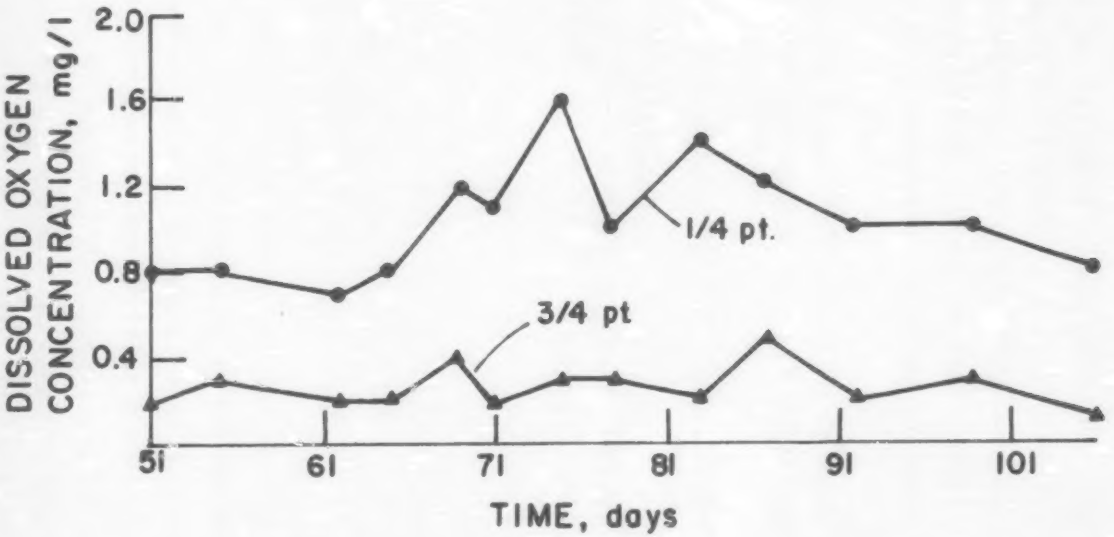


Figure 16. Dissolved oxygen concentrations in Ditch I at the oxygen transfer capacity of 351 gms $O_2$/1000 bird-hours

the absence of the microorganisms, was the probable cause for the lack of significant nitrification.

During this time period, the average mixed liquor ammonia concentration was 1265 mg/ℓ at an average pH of 8.1. The average free ammonia ($NH_3$-N) concentration was 43.7 mg/ℓ. This relatively high free $NH_3$-N concentration and the strong odor of ammonia in the immediate vicinity of the aeration unit suggests that ammonia stripping was the major method of nitrogen removal at this level of oxygen input. Mixed liquor concentrations of total and free ammonia plus pH are presented in Figure 17.

Table 22. RELATIONSHIPS BETWEEN OXYGEN TRANSFERRED AND REMOVAL EFFICIENCIES OF ORGANIC AND TOTAL NITROGEN

| Oxygen Transfer Capacity gms/1000-bird-hrs. | SRT, days | Removal Efficiencies, % Organic Nitrogen | Removal Efficiencies, % Total Nitrogen |
|---|---|---|---|
| 351 | 15 | 55.0 | 48.8 |
| 520 | 21 | 60.4 | 60.4 |
| 815 | 27 | 64.7 | 47.7 |
| 790 | 36.5 | 63.3 | 63.3 |

As shown in Table 22, the removal of total nitrogen was less than that for organic nitrogen during the balance period. The difference was due to the increase of ammonia in the total system, oxidation ditch plus settling tanks, over the balance period. This was due to increased ammonia concentration in the contents of both the ditch and settling tanks. Refilling the settling tanks with tap water following sludge removal on day 78 added to the ammonia storage capacity. Table 23 shows the increase in mass of ammonia in the total system with time.

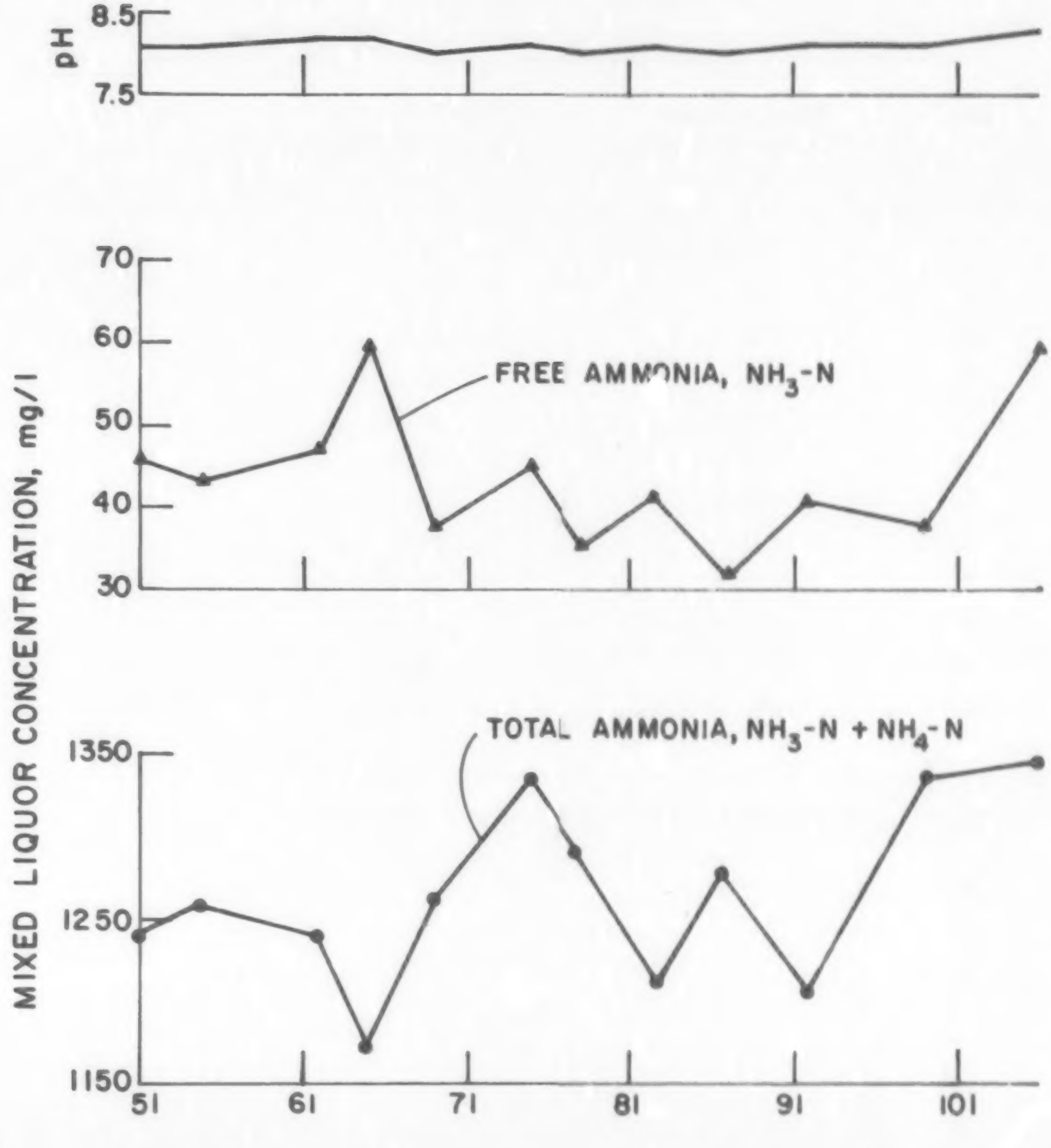


Figure 17. Mixed liquor concentrations of total and free ammonia plus pH at the oxygen transfer capacity of 351 gms $O_2$/1000 bird-hours

Table 23. CHANGE IN MASS OF AMMONIA NITROGEN IN DITCH I AT 351 GMS $O_2$ TRANSFERRED/1000 BIRD-HRS

| Day | Mixed Liquor Ammonia-Nitrogen, kg. | Settling Tank Ammonia-Nitrogen, kg. | Total Mass, kg. |
|---|---|---|---|
| 51 | 131.3 | 37.1 | 168.4 |
| 55 | 133.5 | 41.6 | 175.1 |
| 62 | 131.3 | 45.0 | 176.3 |
| 65 | 126.1 | 45.8 | 171.3 |
| 69 | 133.5 | 48.2 | 181.7 |
| 75 | 141.4 | 50.5 | 191.9 |
| 78 | 136.5 | 0* | 136.5 |
| 83 | 128.3 | 44.5 | 172.8 |
| 87 | 135.8 | 46.6 | 182.4 |
| 92 | 127.6 | 46.6 | 174.2 |
| 99 | 141.4 | 48.0 | 189.7 |
| 106 | 141.7 | 51.4 | 192.8 |

*Settling tanks emptied and refilled with tap water b - Nitrogen removal at 520 gms $O_2$ per 1000 bird-hours - Following the period of lowest oxygen input, the level of oxygen transfer in Ditch I was increased from 351 to 520 gms $O_2$ per 1000 bird-hours. Significant nitrification occurred, as evidenced by a continuous reduction of the mixed liquor ammonia concentration (Figure 18). Trace amounts of $NO_2$-N were present in the mixed liquor throughout this period but $NO_3$-N was not observed.

Although some of the nitrogen loss can be attributed to ammonia stripping, the potential for desorption decreased with time as the free ammonia concentration decreased (Figure 18). Mixed liquor dissolved oxygen concentrations (Figure 19) did not significantly differ from those during the period of lower oxygen transfer (Figure 16). One factor which may explain the low DO levels is the additional nitrogenous oxygen demand (NOD) from the residual ammonia in the system. Combining the quantity of ammonia produced from the degradation of organic nitrogen added during this period with the reduction of the ammonia residual, it was calculated that 150 percent of the NOD was satisfied.

c - Nitrogen removal at higher oxygen inputs - Nitrogen losses were determined for two separate time periods at higher levels of oxygen transfer in Ditch II. The oxygen inputs were 815 and 790 gms $O_2$ per 1000 bird-hrs. during the first and second balance periods.

During the first mass balance period at 815 gms $O_2$ per 1000 bird-hrs., the loss of total nitrogen was less than that of organic nitrogen (Table 22). Accumulation of inorganic nitrogen in the system as ammonia, nitrite, and nitrate was responsible for the difference. Mixed liquor concentrations of these compounds are presented in the segment of Figure 15 denoted balance period (days 91 to 124). Both $NH_4$-N and $NO_2$-N concentrations representing unsatisfied nitrogenous oxygen demand, increased during the balance period. Concurrently, mixed liquor dissolved oxygen concentrations also increased (Figure 20).

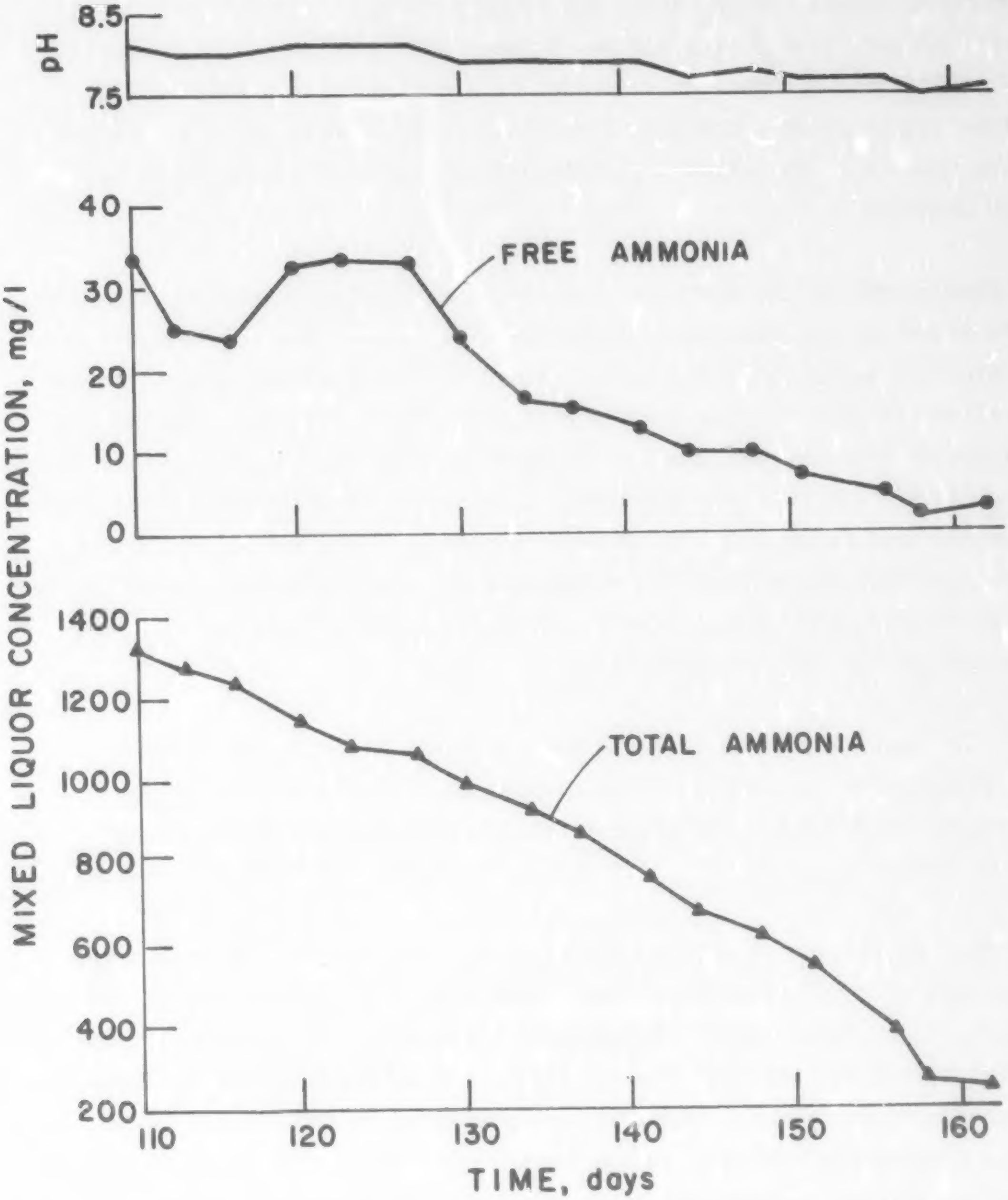


Figure 18. Mixed liquor concentrations of total and free ammonia plus pH at the oxygen transfer capacity of 520 gms $O_2$/1000 bird-hours

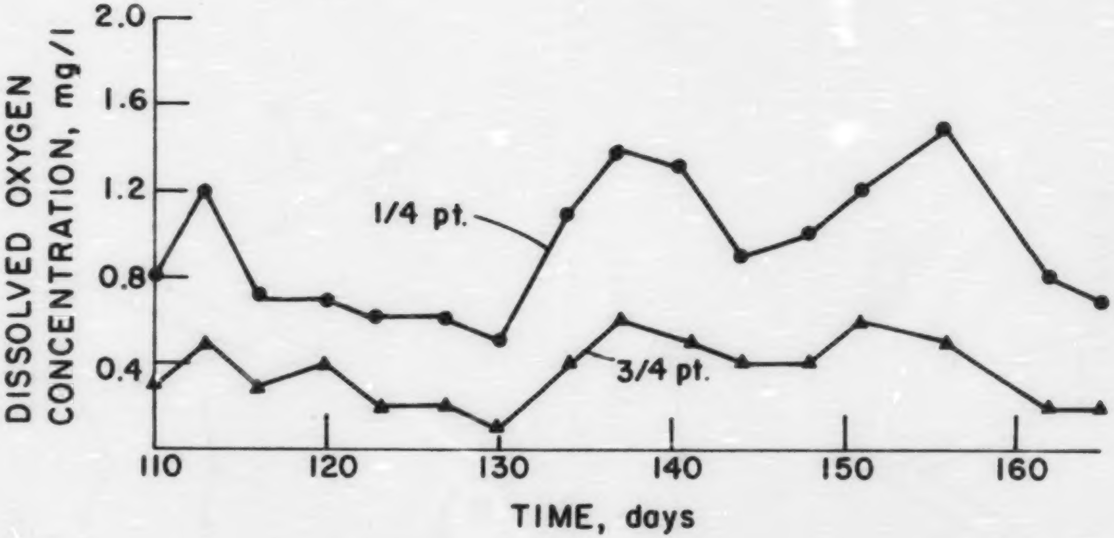


Figure 19. Dissolved oxygen concentrations in Ditch I at the oxygen transfer capacity of 520 gms $0_2$/1000 bird-hours

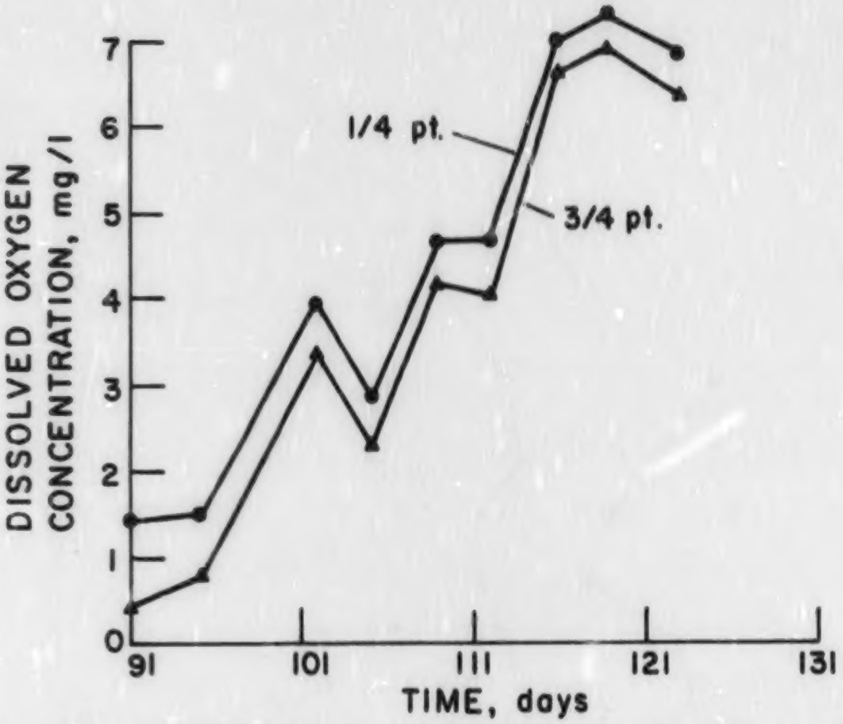


Figure 20. Dissolved oxygen concentrations in Ditch II at the oxygen transfer capacity of 520 gms $O_2$/1000 bird-hours

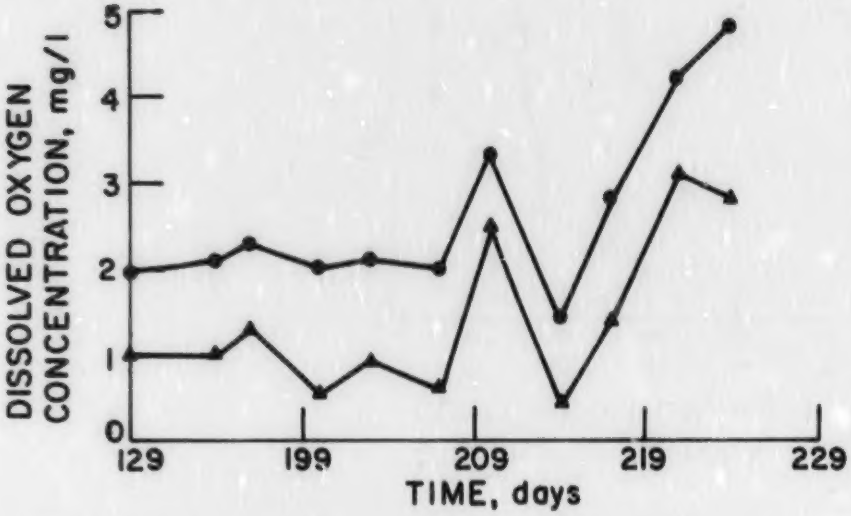


Figure 21. Dissolved oxygen concentrations in Ditch II at the oxygen transfer capacity of 790 gms $O_2$/1000 bird-hours

During the second mass balance period, 790 gms $O_2$ per 1000 bird-hours, removal of organic and total nitrogen was equal (Table 22). No accumulation of inorganic nitrogen occurred and concentrations of $NH_4$-N, $NO_2$-N, and $NO_3$-N remained near zero throughout the balance period. Mixed liquor dissolved oxygen concentrations are presented in Figure 21.

Liquid-Solids Separation -

A key aspect of the systems design approach used at Manorcrest was the removal of residual solids in order to control mixed liquor total solids (MLTS) concentrations. The settling system did permit maintenance of MLTS concentrations at levels below 25,000 mg/ℓ and provided equilibrium conditions to examine the relationship between SRT and treatment efficiency. However, overall performance of the settling system was not satisfactory. It was not possible to develop any clear relationship between overflow rates and removal of solids due to variation in performance.

a - Gravitational settling - The poor settling performance was due in part to the combination of liquid solids separation and sludge storage. Gasification from denitrification and/or anaerobic processes resulted in a floating layer of solids and pin floc. Since the settling tank overflow pipe was 0.6 m (2 ft.) below the liquid surface, the floating solids did not present any problems with respect to clarification. However, these floating solids including feathers formed a mat which was extremely difficult to remove when the tanks were emptied. The pin flocs were carried in the overflow reducing the solids removal efficiency.

Although these problems were significant, observations indicated that the cause of the poor performance was more fundamental in nature, specifically the liquid-solid separation characteristics of aerated poultry wastes. Comparison of settling efficiency at two different mixed liquor total solids concentrations (MLTS) indicated the existence of a relationship between total solids concentrations and settling characteristics.

Comparisons of mixed liquor and settling tank overflow total solids concentrations at two different MLTS concentrations are presented in Figures 22 and 23. In both instances, the settling tanks had been in operation for 3 days prior to the first data point presented. At MLTS concentrations below 12,000 mg/ℓ, the total solids concentrations in the settling tank overflow remained low over the first 20 days of operation (Figure 22). In contrast at MLTS concentrations above 18,000 mg/ℓ, settling tank overflow total solids concentrations increased rapidly (Figure 23).

In order to gain a clearer understanding of the settling characteristics of aerated poultry wastes, the relationship of settling velocity to MLTS was examined over a wide range of MLTS concentrations. This study was conducted at the AWML using aerated poultry wastes from the pilot plant scale oxidation ditch located in that facility.

The range of MLTS concentrations evaluated in the settling tests was 3000 to 13,000 mg/ℓ. Both flocculent settling and zone settling were observed. Flocculent settling occurred at MLTS concentrations below 6,000 mg/ℓ. No attempt was made to quantify the flocculent settling characteristics of the wastewater. At MLTS concentrations greater than 6,000 mg/ℓ, classical zone settling occurred with a distinct interface between the clarified supernatant and the sludge. A typical batch settling curve is presented in Figure 24. The zone settling velocity (ZSV) for each batch settling test was determined by calculating the slope of the steepest portion of the curve as indicated in the Figure. The combined results of the individual batch settling tests are presented in Figure 25. As shown, ZSV decreased dramatically at MLTS concentrations greater than 11,000 mg/ℓ. These values were less than 1 cm/hr. The data exhibited significant scatter. Possible explanations for the scatter are wall effects since a 1000 ml graduated cylinder was used for the tests and the absence of stirring to break up bridged solids that may have occurred during settling.

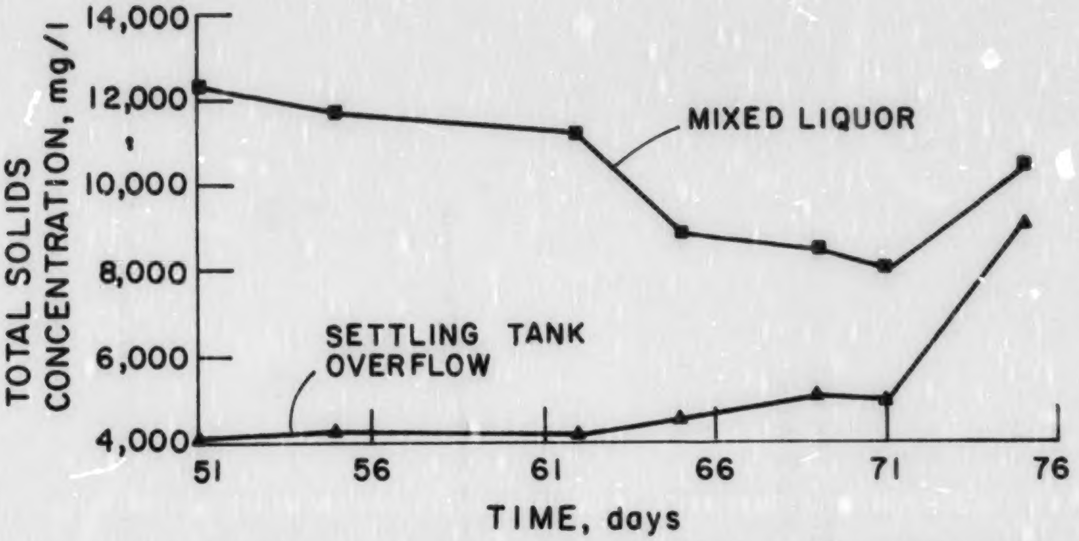


Figure 22. Comparison of mixed liquor and settling tank overflow total solids concentrations at MLTS concentration below 12,000 mg/ℓ

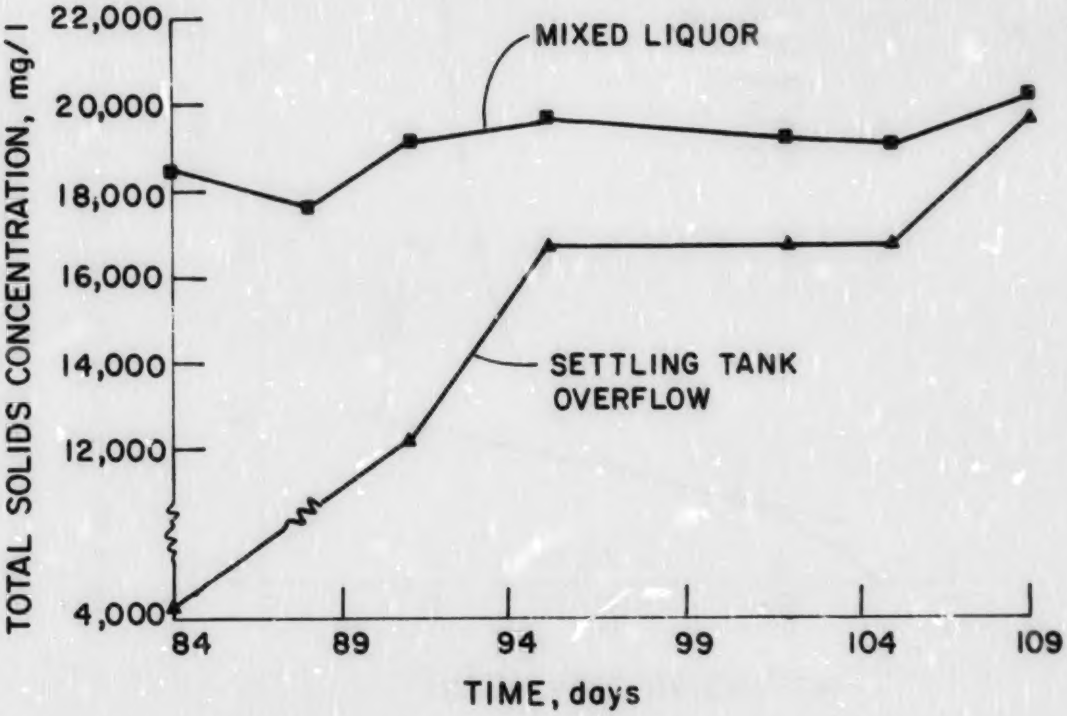


Figure 23. Comparison of mixed liquor and settling tank overflow total solids concentrations at MLTS concentration above 18,000 mg/ℓ

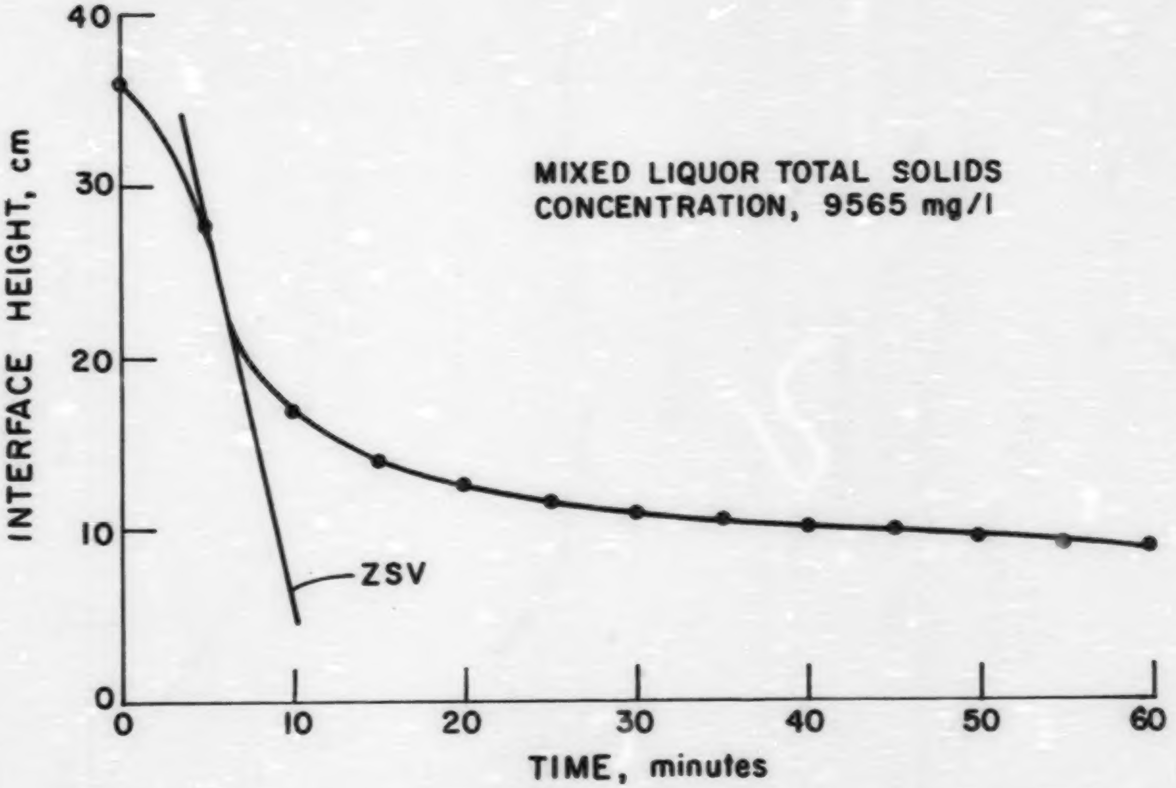


Figure 24. Typical results from a batch settling test, aerated poultry wastes

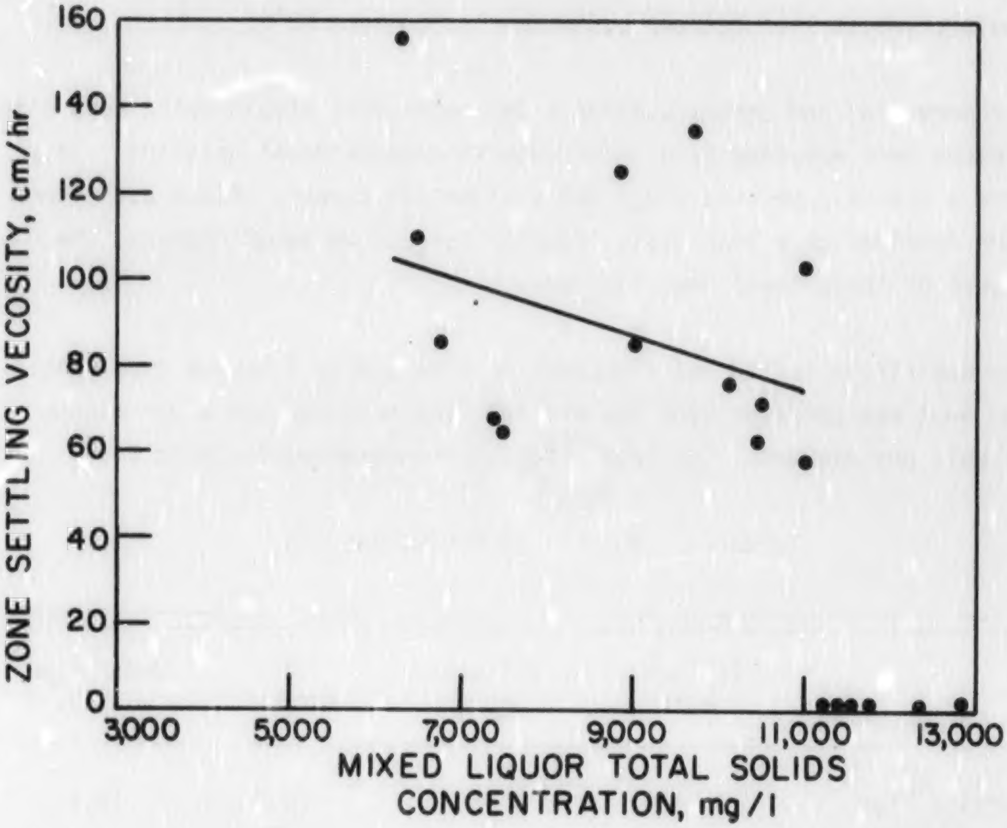


Figure 25. Zone settling velocity versus total solids concentration in aerated poultry wastes

The settling data collected also permitted the calculation of sludge volume indices (SVI) at various MLTS concentrations. Total solids were used in place of total suspended solids in the calculation. The lowest SVI's were observed between 6,000 and 11,000 mg/ℓ MLTS (Figure 26). The results from both the SVI and ZSV determinations indicated that the range for optimum gravitational liquid-solids separation of aerated poultry wastes lies between 6,000 and 11,000 mg/ℓ MLTS.

b - Screening and centrifugation - Two mechanical liquid-solid separation devices were examined as alternatives to gravitational settling. They were a basket type centrifuge and a vibrating screen. Since both items were obtained on a loan basis from the respective manufacturers, the extent of these tests was limited.

The centrifuge tested was a DeLaval 30.5 cm (12 in.) basket type unit. The unit was operated 2750 rpm and the flow rate was 3.8 ℓ per minute (1 gal. per minute). The test results are presented in Table 24.

Table 24. RESULTS OF CENTRIFUGE TEST

| | Influent, mg/ℓ | Effluent, mg/ℓ | % Removal | Under flow solids, % |
|---|---|---|---|---|
| Total solids | 14,150 | 3,530 | 75.0 | 15.8 |
| Volatile solids | 9,078 | 1,652 | 81.8 | 11.7 |

The underflow solids were semi-solid, and it appeared that they could be handled with solid manure handling equipment.

The vibrating screen tested was a 46 cm (18 in.) Sweco Vibro-Energy Separator that can be operated in a single or multiple stage mode with screens placed in series. The vibrational motion of this unit is derived

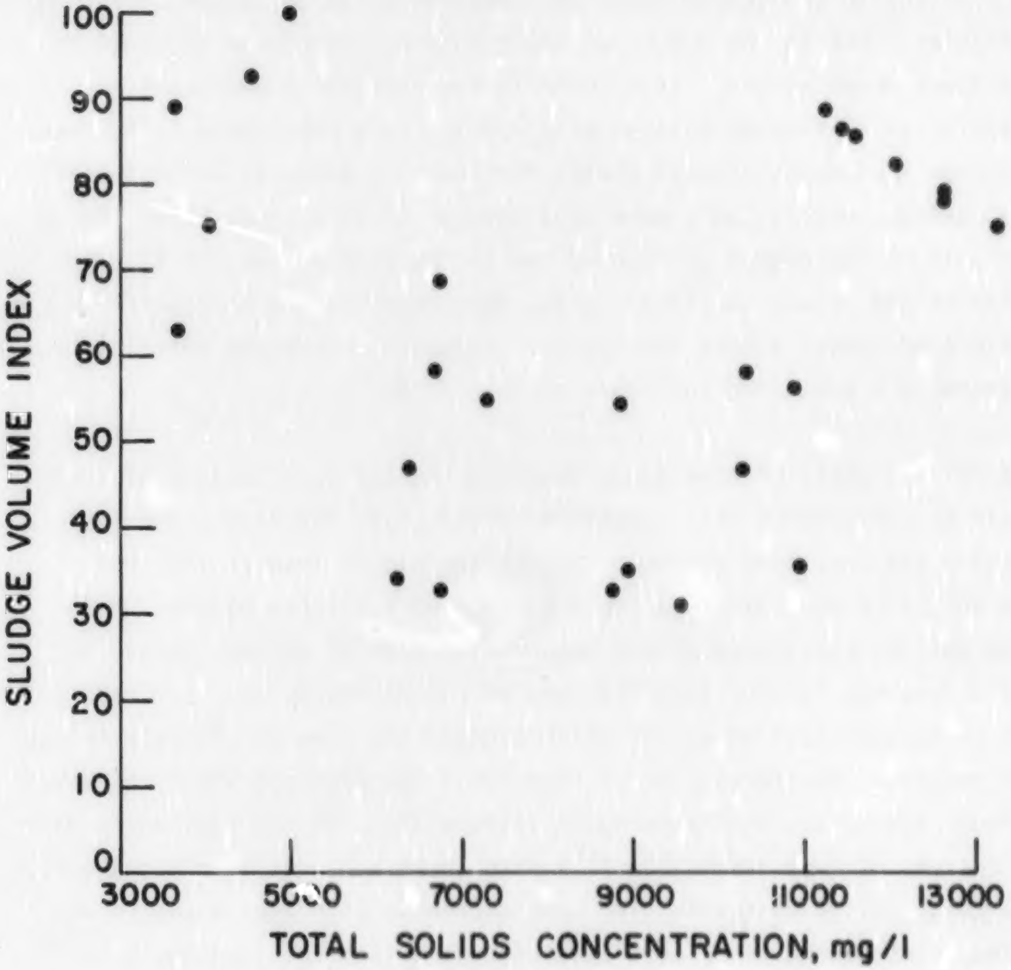


Figure 26. Sludge volume index versus total solids concentration in aerated poultry wastes

from the interaction of suspension springs and rotating weights. Figure 27 is a vertical section of the unit.

Three different mesh size screens; 200, 250, and 325 were evaluated. In addition to the screen size, the Sweco unit has two other operating variables. One is the number of additional weight plates attached to the lower motor weight. This controls the vertical movement of the material as it travels horizontally across the screen cloth. The manufacturer recommends several plates for heavy, coarse, or wet material. The maximum number, four, were used throughout this study. The second variable is the degree of lead of the bottom with respect to the top motor weight, i.e., the lead angle. This controls the horizontal pattern of travel across the screen. Examples of average material travel patterns are presented in Figure 28.

The initial phase of this study investigated the relationship of lead angle to performance for a constant screen size, 200 mesh. The test results are presented in Table 25. At the higher lead angles, 45° and 60°, flow was restricted to a maximum of 6.7 ℓ per minute. When flow was increased beyond this amount, the rate of solids loading to the screen was greater than the rate of solids discharge. The result was an accumulation of solids which blocked the flow of filtrate through the screen. Therefore, a major portion of the flow was short circuited through the solids discharge spout (Figure 27). As the lead angle was decreased, maximum permisible flow rate increased. At all lead angles, the total solids content of the cake decreased with increasing flow rates. Subsequent tests were conducted at a constant lead angle of 0° and flow rate of 13.3 ℓ (3.5 gal.) per minute.

The objectives of these subsequent tests were to examine the relationships of total suspended solids (TSS) concentrations to performance and the effect of screen size on TSS removal. Performance was evaluated in terms of TSS removal and the dry matter content of the separated solids. The results of these tests are presented in Table 26. Single stage screening

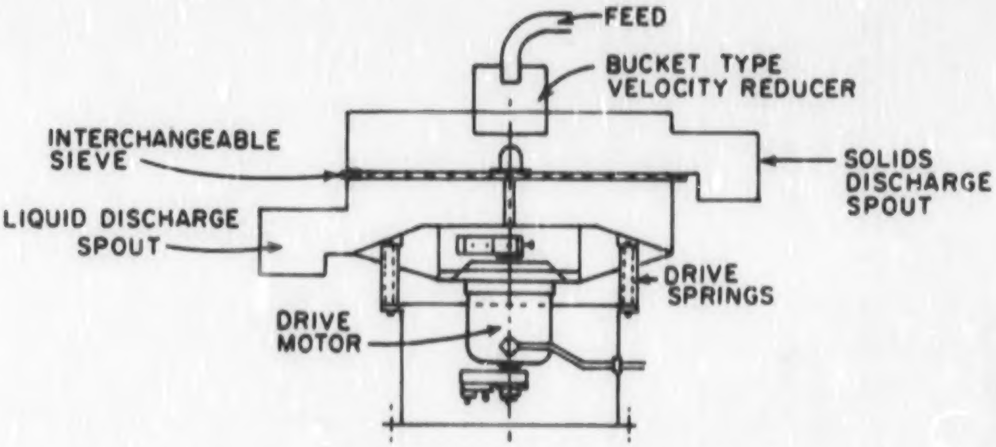
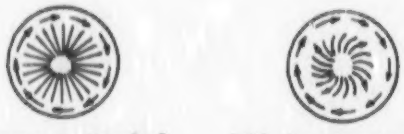
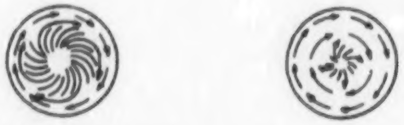

FEED
BUCKET TYPE
VELOCITY REDUCER
INTERCHANGEABLE
SIEVE
SOLIDS
DISCHARGE
SPOUT
LIQUID DISCHARGE
SPOUT
DRIVE
SPRINGS
DRIVE
MOTOR

Figure 27. Vertical section through a basic single deck, 18 inch Sweco Vibrating Screen Separator



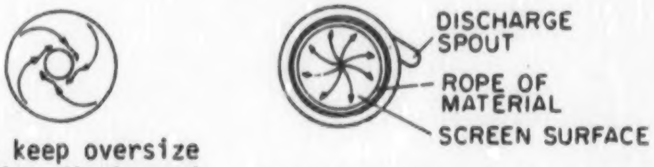
0° Lead-average material may be thrown straight and may give insufficient separation

15° Lead-average material may begin to spiral



40° Lead-may give average dry material maximum efficient screening pattern

60° Lead-may give average wet material maximum effecient screening pattern


DISCHARGE
SPOUT
ROPE OF
MATERIAL
SCREEN SURFACE

Maximum lead may keep oversize material from being discharged and assist in receiving maximum thruput of minus material which tends to "ball"

Roping pattern on the screen

Figure 28. Illustration of average material travel on the screen

Table 25. RELATIONSHIP BETWEEN LEAD ANGLE AND PERFORMANCE
200 MESH SCREEN, 0.074 mm

| Average Influent Total Suspended Solids Concentration, | Lead Angle | Flow Rate, ℓ/min. | Percent Removal Total Suspended Solids | Cake Percent Total Solids |
|---|---|---|---|---|
| 1970 | 60° | 2.5 | 23.5 | 11.9 |
|  |  | 4.0 | 24.8 | 10.6 |
|  |  | 6.7 | 17.6 | 9.0 |
|  | 45° | 2.5 | 29.3 | 11.7 |
|  |  | 4.0 | 34.0 | 10.7 |
|  |  | 6.7 | 22.1 | 9.0 |
| 2800 | 30° | 5.7 | 37.1 | 13.3 |
|  |  | 13.3 | 36.2 | 10.7 |
| 4890 | 15° | 2.0 | 34.8 | 12.2 |
|  |  | 13.3 | 34.5 | 11.4 |
|  | 0° | 4.0 | 27.4 | 13.2 |
|  |  | 8.0 | 22.9 | 11.5 |
|  |  | 13.3 | 24.8 | 11.1 |

## Table 26. RESULTS OF SINGLE AND TWO STAGE SCREENING TRIALS

| Screen Mesh No. | Size, mm. | Feed Solids Concentration, mg/ℓ. Total Solids | Feed Solids Concentration, mg/ℓ. Total Suspended Solids | Filtrate Total Suspended Solids, mg/ℓ | Filtrate % Removal of Total Suspended Solids | Cake Dry Matter Content Percent |
|---|---|---|---|---|---|---|
| 1 Stage | | | | | | |
| 200 | 0.074 | 4,512 | 1,974 | 1,302 | 34.0 | 10.6 |
| | | 5,228 | 2,425 | 1,811 | 35.4 | 10.2 |
| | | 9,575 | 5,015 | 3,865 | 22.9 | 11.5 |
| | | 23,625 | 17,676 | 13,364 | 24.8 | 11.1 |
| 2 Stage | | | | | | |
| 200 plus | 0.074 | 9,325 | 4,763 | 3,748 | 21.3 | 15.4 |
| 250 | 0.062 | ↓ | ↓ | 3,678 | 22.8 | 11.0 |
| 200 plus | 0.074 | ↓ | ↓ | 3,758 | 21.1 | 15.4 |
| 325 | 0.044 | ↓ | ↓ | 3,249 | 31.8 | 2.7 |

trials were conducted with 200, 250, and 325 mesh screens over a range of TSS from 1,302 to 13,364 mg/ℓ. Performance of the 250 and 325 mesh screens individually were unsatisfactory since the flow was limited to low rates with these screens. The results from the single stage trials (Table 26) indicate that removal of TSS decreased as influent TS and TSS concentrations increased. The separated solids consisted of coarse materials such as seed coats, feed, and feather parts. The cake was semi-solid similar to wet sawdust and appeared amenable to handling as a solid.

Two stage screening tests were conducted using combinations of 200 plus 250 and 200 plus 325 mesh screens in series. The addition of the 250 mesh screen only nominally increased TSS removal (Table 26). Although the dry matter content of the cake from the 250 mesh screen, 11.0 percent was similar to that of the separated solids from the single stage 200 mesh tests, the physical appearance differed. The 325 mesh screen increased TSS removal by 11.2 percent over the first stage 200 mesh screen with a total TSS removal of 31.8 percent.

## PROBLEMS IDENTIFIED

### Introduction

One of the objectives of this study was to identify problem areas in the design and operation of aeration systems for poultry wastes. During the course of the investigation, several problems were encountered. They include equipment breakdowns, sedimentation of solids in both ditches, foaming, feathers, and excess water leakage from the bird watering system. The first two items placed constraints on the evaluation of the system performance.

### Equipment Problems

The major equipment problem involved the Thrive Centers cage rotor in Ditch II. The most frequent problem was failure of connection 1 to 2 between the paddle bar and wheel plate assembly (Figure 29).

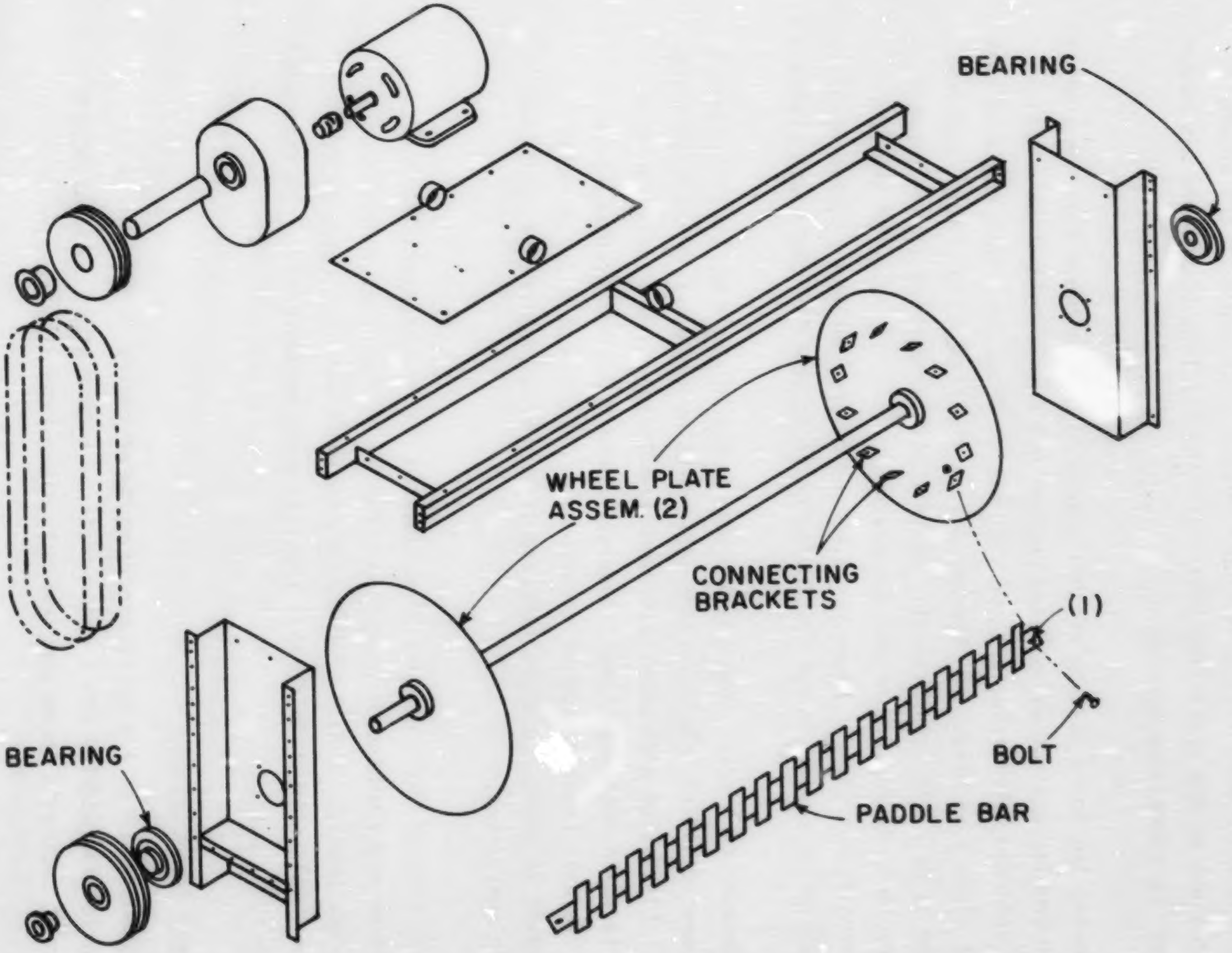

BEARING
WHEEL PLATE ASSEM. (2)
CONNECTING BRACKETS
(1)
BOLT
BEARING
PADDLE BAR

Figure 29. Assembly diagram of a Thrive Center Cage Rotor

Two types of failure occurred. They involved shearing of the connecting brackets, which were flat plates butt welded to the wheel plate assembly, and failure of the connecting bolt. The initial type of failure was shearing of the connecting brackets.

Following the third failure of this type, it was concluded that the bracket shear problem was not an isolated problem but involved inadequate design. Upon informing Thrive Centers, Inc. of the difficulties, they replaced both wheel plate assemblies. On the new units, the flat plate bracket was replaced by an angle iron bracket. At this point, shearing of the brackets was replaced by failure of the connecting bolts. The cause of the bolt failures is not clear. However, it may be related to over tightening of certain bolts during reassembly following replacement of the wheel plates.

The problem of bracket shearing was due to a design change by Thrive which has been rectified. Bolt failure appears to be isolated to the Manorcrest unit. Discussion with other owners of the Thrive rotors indicates that this is not a common problem. However, these and other problems such as drive belt breakage caused aeration to be interrupted for periods exceeding 24 hours, on eight separate occasions during the 19 months of system monitoring.

The bearings of both aerators were replaced due to deterioration following the first eight months of operation. During this period, lubrication was performed weekly. A daily lubrication schedule was instituted following bearing replacement. No further problems were encountered in the remainder of the study period.

### Sediment Accumulations

The accumulation of a significant quantity of solids in the bottom of both oxidation ditches was a major problem in this study. As the accumulation of sediments increased, the velocity of the mixed liquor decreased to the point of a complete stoppage of circulation. This occurred several times in Ditch II requiring the complete removal of the ditch contents. Conversely, circulation in Ditch I was always maintained although velocity did decrease with sediment accumulation.

Sediment accumulations were first measured in April 1974, when Ditch II velocities were approaching zero. At this time, Ditch II had been in operation for 8 months. A profile of the measured sediments is presented in Figure 30. Based upon the sediment measurements, it was calculated that 30 percent of the ditch liquid volume was occupied by settled solids. At this time, it was necessary to empty the ditch to facilitate the replacement of the Thrive rotor wheel assemblies. At this time, accumulated sediments were removed. This permitted reestablishment of ditch circulation through the end of the laying cycle, August 1974.

Sediment accumulation was measured in Ditch I after 10.5 months of operation. The sediment profile is presented in Figure 31. The volume of accumulated solids was 22 percent of the liquid volume. This indicates that Ditch I had a lower rate of solids deposition since the accumulated quantity was less than that in Ditch II and period of operation was longer.

Prior to the beginning of the second year of operation, the accumulated sediments in both ditches were completely removed. The liquid depth was reduced from 50.8 cm (20 in.) to 33 cm (13 in.). The objective was to reduce the cross-sectional area of the liquid. It was assumed that with a constant aerator depth and therefore pumping capacity, the result would be a substantial increase in mixed liquor velocity, since the cross-sectional liquid area was reduced by 35 percent. This reduced the mixed liquor volume from 105,980 ℓ (28,000 gal.) to 68,887 ℓ (18,200 gal.). Initial velocities under these conditions were 0.36 m/sec (1.2 ft/sec) and 0.43 m/sec (1.4 ft/sec) for Ditches I and II. A comparison of initial velocities for years I and II are presented in Table 27.

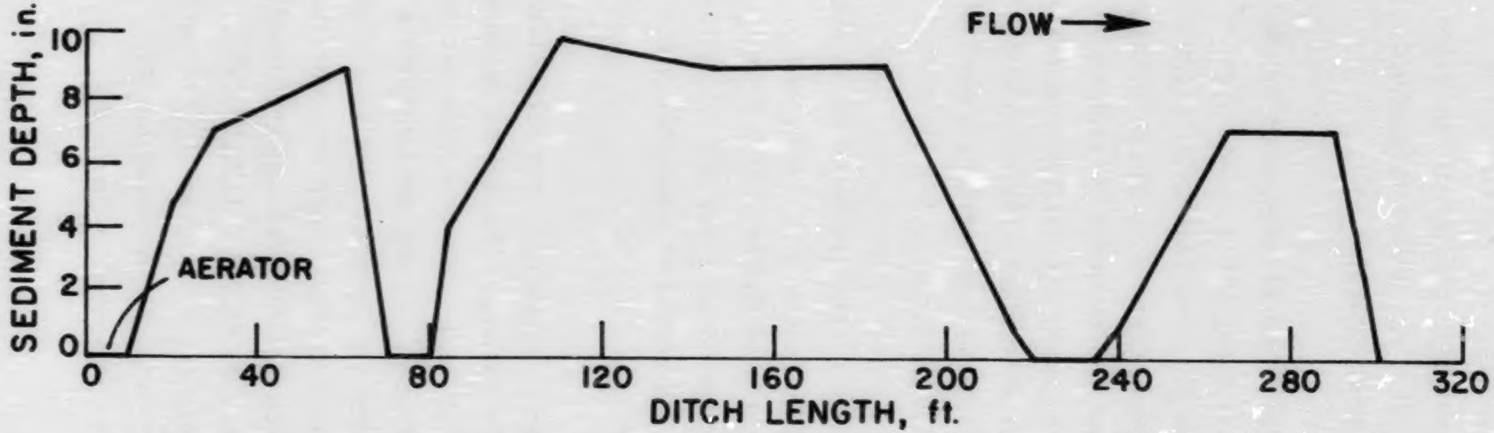


Figure 30. Sediment profile in Oxidation Ditch II, 1973-74

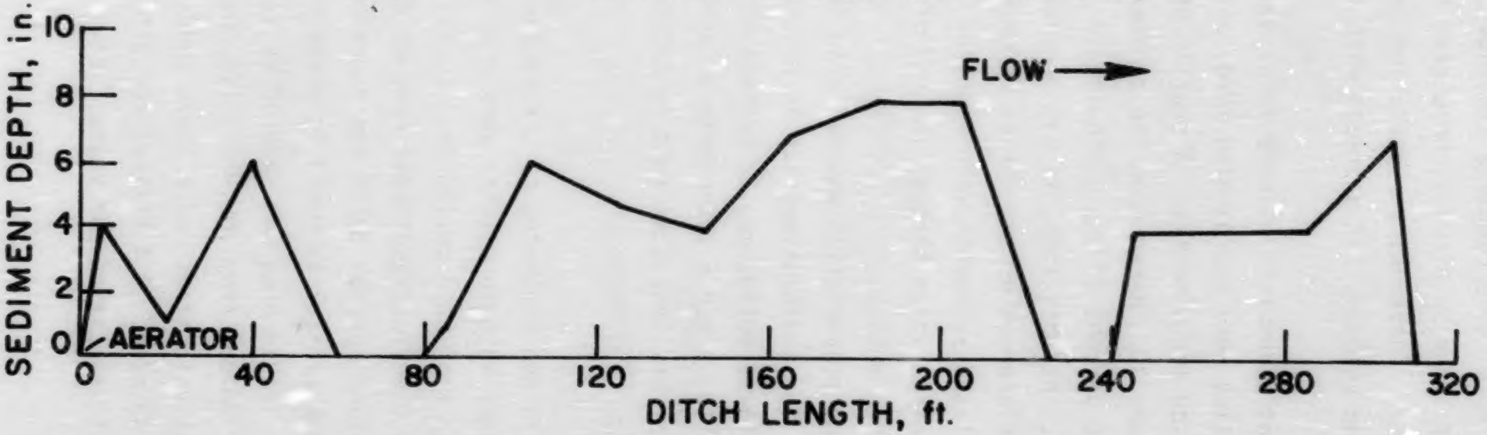


Figure 31. Sediment profile in Oxidation Ditch I, 1973-74

Table 27. COMPARISON OF INITIAL DITCH VELOCITIES AT VOLUMES OF 68,887 ℓ AND 105,980 ℓ

| | Year I (105,980 ℓ) | Year II (68,887 ℓ) |
|---|---|---|
| Ditch I | 0.26 m/sec. | 0.36 m/sec. |
| Ditch II | 0.38 m/sec. | 0.43 m/sec. |

The problem of sediment accumulation and reduced mix liquor velocity reoccurred under the new operating conditions. Figures 32 and 33 show the profiles of the settled solids at two points in time in each ditch. The profiles indicate a pattern of initial solids accumulation immediately downstream from the aeration unit followed by deposition further downstream. It was necessary to again remove the sediments from Ditch II after 5 months of operation since the mixed liquor circulation had ceased at that time.

Composite samples of the accumulated solids were taken from each ditch when the last sediment measurements were made. The samples were analyzed to characterize their composition. The results of the analyses and comparison to raw manure are given in Table 28.

Table 28. SEDIMENT CHARACTERISTICS

| | Ditch I | Ditch II | Raw Manure, 1974-1975 |
|---|---|---|---|
| % TS | 30.3 | 19.4 | -- |
| $\% \frac{VS}{TS}$ | 30.6 | 49.0 | 72 |
| $\frac{mg\ COD}{mg\ FS}$ | 729 | 1760 | 2544 |

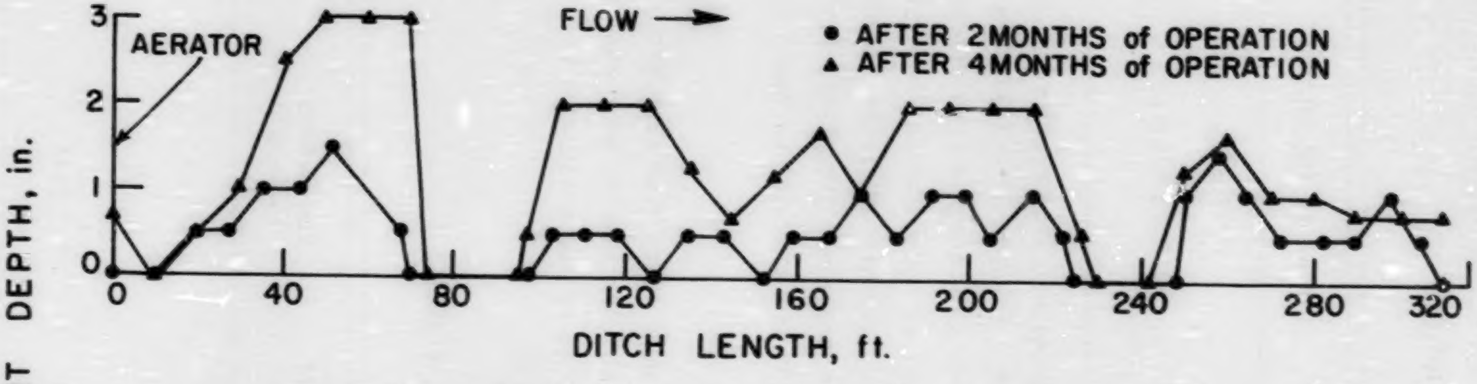


Figure 32. Sediment profile in Oxidation Ditch I, 1974-75

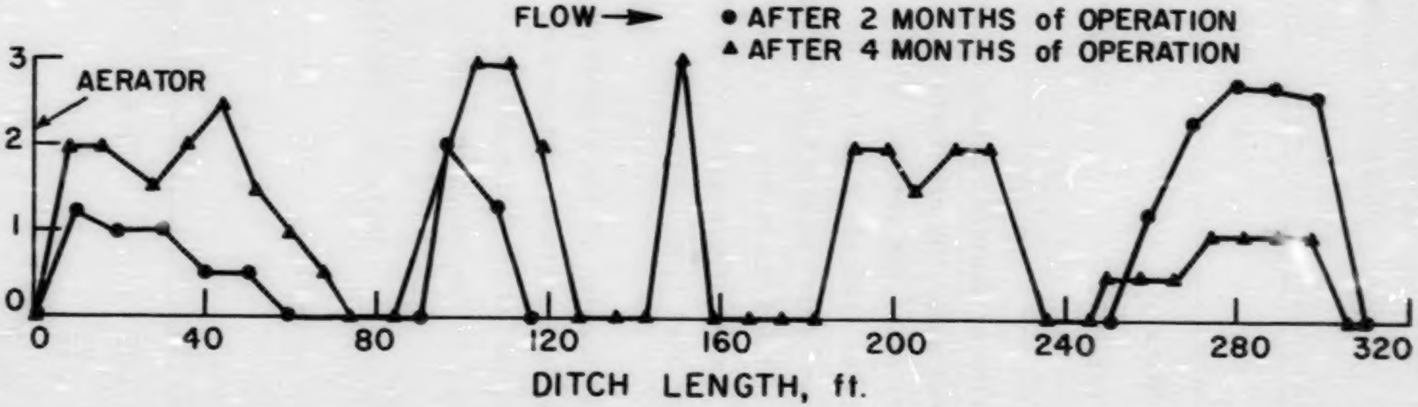


Figure 33. Sediment profile in Oxidation Ditch II, 1974-75

The differences in the sediment characteristics of the two ditches appear to be related to mixed liquor velocities prior to sampling. The velocity of Ditch II was approaching zero at the time of sampling. Raw manure was accumulating on top of the initial sediment layer and was included in the sample. This could account for the higher percentage of volatile solids and the larger COD to fixed solids ratio. The analytical results indicate that sediment in Ditch I consisted primarily of inorganic material.

## Foaming, Feathers, and Excess Water

Foaming problems were encountered during this study. However, these problems were of a nuisance rather than a serious nature. No endangerment of the animals or workers in the building ever occurred. Excessive foaming occurred in Ditch II but not in Ditch I. Therefore, inadequate oxygen supply was discounted as the cause of foaming. Ditch I was a minimally aerated system.

The cause of the foaming problem appeared to be related to the movement of the foam around the ditch. Foam was usually present on this surface of Ditch I in a thin layer or in patches. However, surface velocity was always adequate to maintain continuous movement. Therefore, a constant cycle of foam generation and breakdown by the aerator occurred.

The foaming problems encountered in Ditch II appeared to be related to the interruption of this cycle due to a stoppage in the movement of the foam layer. The principle factor responsible for cessation of foam layer movement was reduction in mixed liquor velocity due to sediment accumulation. Because of minimal friction between the foam layer and the mixed liquor surface, the ditch sidewalls were adequate to stop foam movement as mixed liquor velocities decreased. Therefore, the cycle of foam generation and breakdown was interrupted. Generation of foam continued with the resulting accumulation causing an overflow onto the service aisles on several occasions. Used motor oil was added to Ditch II to control foam during the first year. When the liquid depth was decreased to 33 cm (13 in.) at the beginning of the second year, freeboard increased to 41 cm (16 in.). This was adequate to contain the foam, and oil additions were not necessary.

The role of the accumulated sediments to the foaming problem is unclear. Both ditches had significant accumulations of these sediments, but foaming problems only occurred in Ditch II.

Feathers were another problem. Initially, the feathers were allowed to move through the overflow standpipes into the settling tanks. However, they accumulated in the first settling tank and formed a floating mat. On several occasions, this mat blocked flow through the standpipes. When the settling tanks were emptied, it was necessary to remove the feathers manually using rakes and shovels.

To eliminate the reoccurrence of this problem, baffles were installed around the standpipes to exclude the feathers from the settling tanks. This was possible since most of the feathers were on the surface. However, this resulted in the accumulation of large mats of floating feathers which would be stopped by obstructions such as the overflow standpipes or the propeller housing in Ditch I prior to its removal. It was necessary to remove these mats with a rake. This was done in response to accumulation which varied from daily to weekly depending on the rate of feather loss.

Excessive leakage from the bird watering system was greater than evaporative losses. This caused a small overflow from the settling tanks onto the corn fields behind Building No. 1. The frequency and quantity varied due to variation in amount of leakage and changes in evaporative conditions. The watering system consisted of individual watering units known as Hart Cups. Figure 34 is a schematic drawing of a Hart Cup. Operation of the on-off valve, which consisted of a rubber

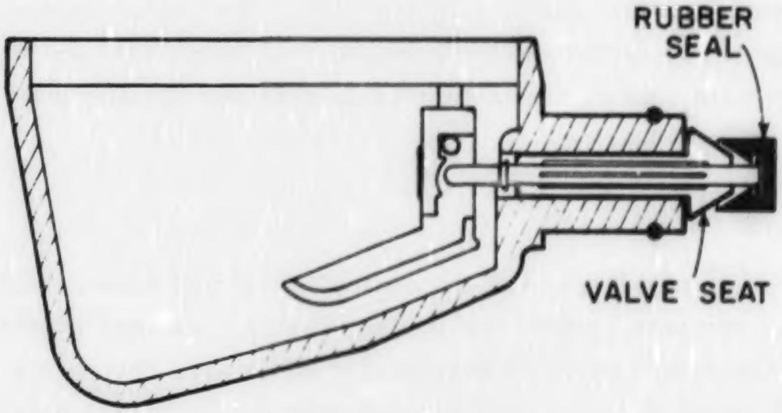

RUBBER SEAL
VALVE SEAT

Figure 34. Cross section of a Hart Cup

seal and seat, is dependent on water pressure. Variations in water pressure caused the units to overflow. Since dilution water was necessary to liquify the manure with the previous management system, leakage was desirable. Therefore, no pressure regulators had been used. Following recognition of the problem, pressure regulators were installed. This reduced but did not completely eliminate the problem.

Overflow of the Hart Cups also occurred when particles, primarily feed, lodged between the rubber seal and seat. This held the valve open causing a drop in water pressure in the line. Then other cups would overflow due to the drop in water pressure. Although the cups were checked daily and repaired when necessary, this was not adequate to control the excess leakage.

## CAPITAL AND OPERATING COSTS

One of the study objectives was the evaluation of the economic impact of utilizing aeration systems for poultry wastes. In keeping with this objective, the major capital and operating costs were determined. Capital and operating costs were not constant due to differences in aeration equipment and methods of operation. Each situation was examined individually.

The capital costs for the two oxidation ditches included costs for the modification of the existing pits, settling and storage tanks, and aeration equipment. The modification costs were the labor and materials for the conversion of the existing manure collection pits into two oxidation ditch channels and the equipment installation including necessary electrical modifications. Settling tank costs included labor for excavation, tank placement, and backfilling. The cost of the industrial propeller originally used in Ditch I was excluded since it was found to be ineffective and was removed from the system.

Table 29 contains the initial cost, estimated useful life, and annual cost for each capital item. These figures were used to determine the total and annual capital costs for each oxidation ditch which are presented in Table 30. Construction costs were equal for each ditch. The difference in aerator costs is responsible for the overall differences between the two ditches.

The operating costs examined included power, maintenance and repairs, and taxes and insurance. Power costs varied with the level of oxygen transfer and each situation was examined independently. The numerous mechanical problems encountered in this study made estimation of maintenance and repair costs extremely difficult. The number of mechanical problems encountered in this study do not appear to be representative. Therefore, maintenance and repair costs were estimated at 2 percent of the total initial investment for each ditch. This appears reasonable since daily maintenance was minimal consisting only of bearing lubrication which was done during feeding or egg collection. Yearly bearing replacement has been shown to be the major repair item in other experiences with similar systems. Taxes and insurance were estimated to be 3 1/2 percent of the annual capital cost.

Energy costs at the three different levels of oxygen transfer examined in this study are presented in Table 31. A summary of the overall operating costs are presented in Table 32. As shown, energy is the major operating cost, comprising 60 to 73 percent of total operating costs. Differences in maintenance and repair costs and insurance and taxes betweeen the two ditches were small. Problems in the area of liquid-solids separation precluded a realistic assessment of ultimate disposal costs.

Table 33 contains a total cost summary for aeration of poultry wastes at Manorcrest Farms. As shown, aeration systems are capital intensive with capital costs responsible for 58 to 66 percent of total costs depending on level of oxygen transfer and therefore energy consumption.

Table 29. INITIAL AND ANNUAL CAPITAL COSTS - MANORCREST PROJECT AERATION SYSTEMS COMPONENTS

| | Total Cost* | Estimated Useful Life Years | Annual Cost** |
|---|---|---|---|
| Construction | | | |
| Oxidation Ditches | 8,735 | 20 | 958 |
| Settling Tanks | 3,040 | 20 | 333 |
| Equipment | | | |
| Thrive Center Cage Rotor | 2,120 | 10 | 346 |
| Montair Brush Aerator | 1,500 | 10 | 244 |

* 1973 prices

** Amortized at 9 percent per year over the estimated useful life, no salvage value

Table 30. TOTAL AND ANNUAL CAPITAL COSTS FOR THE MANORCREST AERATION SYSTEMS

| Item | Ditch I | Ditch II |
|---|---|---|
| Capital Costs | | |
| Total | $ 7,388 | $8,008 |
| Per 1,000 hens | 1,847 | 2,002 |
| Annual cost per year | 890 | 992 |
| Annual cost/1,000 hens/year | 222 | 248 |
| Cost per dozen eggs* | .0111 | .0124 |

*Assumes 4,000 hens per ditch and 20 dozen eggs per hen/yr.

Table 31. ENERGY COSTS* FOR AERATION IN RELATION TO THE LEVEL OF OXYGEN TRANSFER

| Level of Oxygen Transfer Capacity, gms $O_2$/1000 bird-hrs. | Ditch No. | Aeration Unit | kwhr/ 1000 hens/yr | Cost/ 1000 hens/yr | Cost/** Dozen Eggs |
|---|---|---|---|---|---|
| 351 | I | Brush Aerator | 3,328 | $ 66.89 | $.0033 |
| 520 | I | Brush Aerator | 4,558 | 91.62 | .0046 |
| 790 & 815 | II | Cage Rotor | 6,524 | 131.14 | .0067 |

* Energy cost of $.0201 per kilowatt-hour

**Assumes 4,000 hens per ditch and 20 dozen eggs per hen-year

## Table 32. OPERATING COSTS FOR MANORCREST AERATION SYSTEMS PER 1,000 HENS PER YEAR

| | Ditch I | | Ditch II |
|---|---|---|---|
| | Oxygen Transfer Capacity, Gms $O_2$/1000 bird-hrs. | | |
| | 351 | 520 | 790 & 815 |
| Energy Costs | 66.89 | 91.62 | 131.14 |
| Maintenance and Repairs | 36.94 | 36.94 | 40.04 |
| Taxes and Insurance | 7.78 | 7.78 | 8.68 |
| Total | 111.61 | 136.34 | 179.86 |
| Cost per Dozen* Eggs | .0056 | .0068 | .0090 |

*Assumes 20 dozen eggs per hen-year

## Table 33. COST SUMMARY OF AERATION OF POULTRY WASTES, MANORCREST FARMS

| | Ditch I | | Ditch II |
|---|---|---|---|
| | Oxygen Transfer Capacity, Gms $O_2$/1,000 Bird-hrs. | | |
| Costs/1,000 hens/year | 351 | 520 | 790 & 815 |
| Annual capital | $ 222 | $ 222 | $ 248 |
| Operating | 112 | 136 | 180 |
| Total | $ 334 | $ 358 | $ 428 |
| Costs/dozen eggs* | | | |
| Annual capital | $.0111 | $.0111 | $.0124 |
| Operating | .0056 | .0068 | .0090 |
| Total | $.0167 | $.0179 | $.0214 |

*Assumes 20 dozen eggs per hen-year

# SECTION VII

# DISCUSSION OF EXPERIMENTAL RESULTS

## GENERAL

The primary objective of this investigation was to demonstrate and evaluate the potential of aerobic treatment to reduce the air and water pollution potential of poultry wastes when employed under commercial conditions. The concepts used in the design and operation of the Manorcrest aeration systems were derived from the results of smaller scale studies. Although the specific goals of odor control, waste stabilization and nitrogen management were achieved, overall system performance was not as perfect as desired. The problems encountered were primarily related to the physical system design. This identified a shortcoming in the design approach which was process oriented.

The problems of sediment accumulation and poor liquid solids separation as well as equipment failures hindered but did not eliminate the demonstration of the process design parameters for aeration systems for poultry wastes.

This section will discuss the results in terms of the process design concepts employed as well as the physical problems encountered and their role in overall systems design. Also included is an evaluation of the economic impact of utilizing aeration systems for waste management in egg production.

## ODOR CONTROL

An objective of this study was to demonstrate the odor control capabilities of the aeration process. Malodors emanating from ventilation systems and wastes spread on the land have been a major point of conflict between egg producers and other rural residents. Elimination of odor problems was demonstrated in this study.

The additional benefit of improved environmental conditions within the building should also be recognized. The elimination of malodors, flies, and other vermin greatly improved the working conditions for the people caring for the birds. This point was frequently cited in discussions about the study with Manorcrest employees. Similar observations were made by members of the Cornell Agricultural Waste Management Program who had visited the site prior to conversion to the aeration systems. The high rise house, Building No. 2, provided some basis for comparisons. Although environmental conditions in that building were superior to the anaerobic liquid manure system previously in Building 1, they were not as good as the conditions in Building No. 1 with aeration. Both employees and visitors to the demonstration site commented on this fact. The additional benefit of improved working conditions appears to be significant in that poor working conditions due to odors, etc., are often identified as a major problem area in attracting good farm labor.

## DESIGN PARAMETERS

The relationship between oxygen transfer and mixed liquor total solids (MLTS) concentration formed the basis for the Manorcrest aeration systems design. The objective was to maximize oxygen transfer by restricting the MLTS concentration to a maximum of 20,000 mg/ℓ. This would maintain $\alpha$ values at or approaching unity. This required removal of residual solids and the use of SRT as a design and operational parameter.

Although the design SRT was based on maintenance of nitrifying conditions, relationships between the degree of stabilization and SRT in aerobically treated poultry wastes had been previously developed (11,16). Variations in SRT due to inconsistent solids removal permitted confirmation of the earlier observations. The results from this study have been presented in Figure 12 through 13. These results were combined with results obtained in a previous study and are presented in Figures 35 through 38.

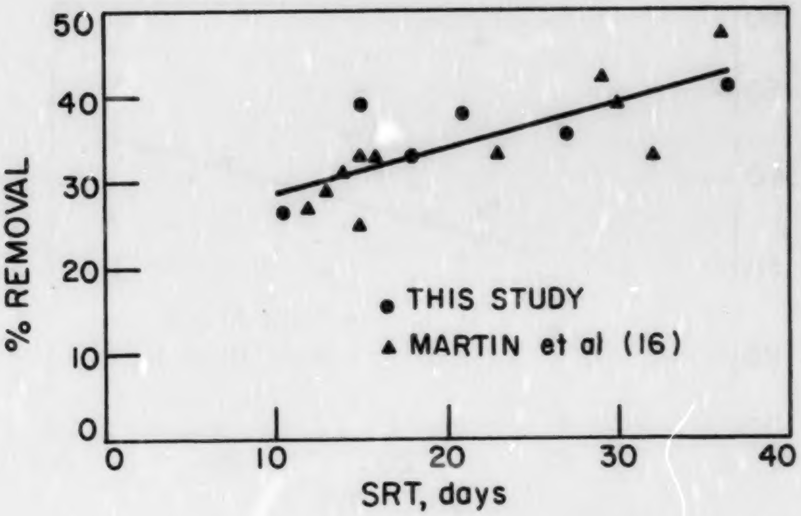


Figure 35. Observed relationship between SRT and removal of total solids in aerated poultry wastes

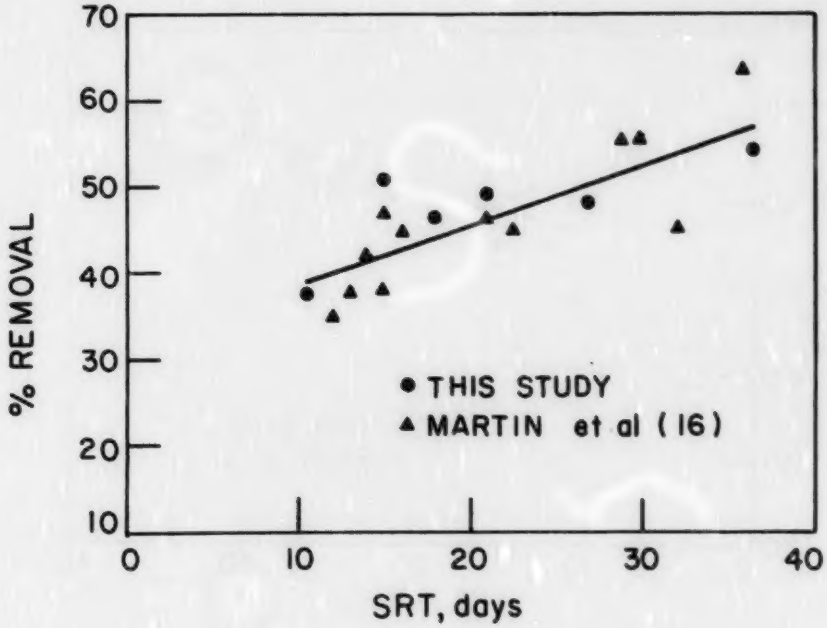


Figure 36. Observed relationship between SRT and removal of volatile solids in aerated poultry wastes

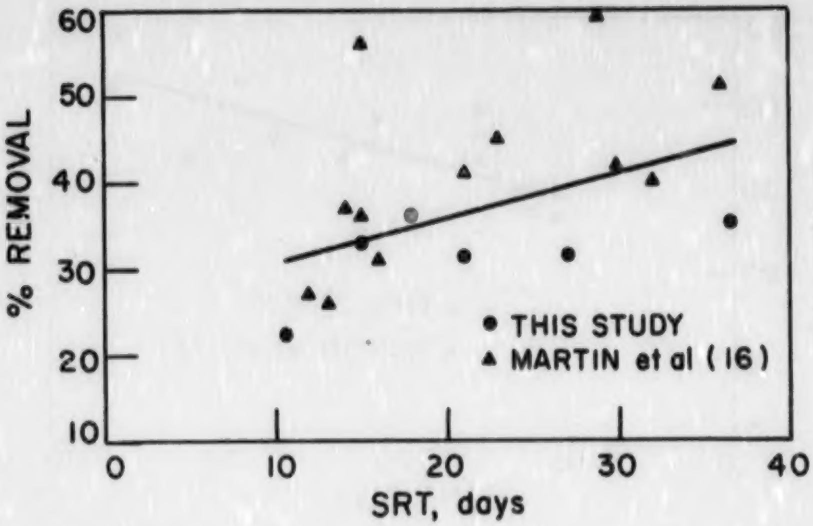


Figure 37. Observed relationship between SRT and removal of COD in aerated poultry wastes

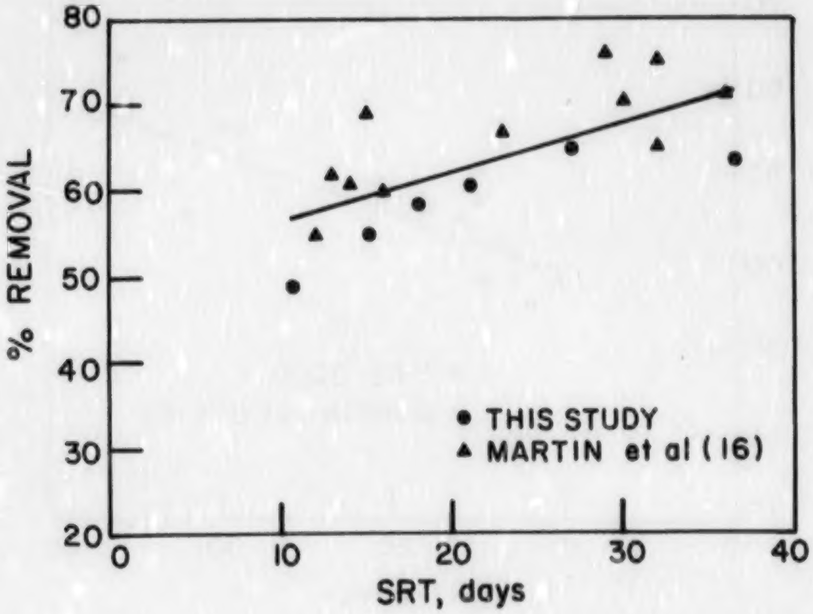


Figure 38. Observed relationship between SRT and removal of organic nitrogen in aerated poultry wastes

There is good agreement between the results of these separate studies. These data serve to define the relationship between removals of total solids, volatile solids, COD, and organic nitrogen and SRT and show that removal increases with SRT. Therefore, regulation of SRT provides a mechanism for control of the degree of stabilization to meet specific objectives. With proper design, it should be possible to limit oxygen requirements necessary to meet exerted carbonaceous oxygen demand and provide odor control. Oxygen requirements for nitrogenous oxygen demand, if nitrification or nitrification-denitrification are part of the overall stabilization objectives, also could be developed using a similar approach.

Oxygen supply was always greater than the exerted carbonaceous oxygen demand in this study (Table 19). No odor problems were encountered even at the lowest level of oxygen transfer, 350 gm $O_2$/1,000 bird-hours. However, the rate of oxygen transfer exceeded the rate of COD removal by 25 percent. Satisfactory odor control has been reported when the estimated rate of oxygen transfer exceeded COD removed by only 2 percent (16). That study also involved the evaluation of aeration of poultry wastes under commercial conditions. Based upon the combined results presented in Figure 37, reduction of SRT from 36.5 to 30 days should reduce oxygen requirements, expressed as COD removed for odor control, by about 19 percent. As shown in Figure 38, the exerted nitrogenous oxygen demand from ammonification of organic nitrogen will also decrease with decreases in SRT.

Due to the interrelationships between SRT and waste stabilization as well as those between SRT and nitrification, it is not possible to specify a single SRT for all aeration systems. Individual situations and waste management objectives must be considered. However, the results of this study (Table 21) and those of a previous study (11) show that most of the soluble COD is removed at an SRT of 10 days. Therefore, a minimum SRT of 10 days should significantly reduce the water pollution potential from soluble carbonaceous compounds. These compounds have the greatest potential for contamination of surface waters via overland flow. Increased removal of total solids, volatile solids, and COD can be achieved by increasing SRT beyond 10 days (Figures 35 through 37). Increase in SRT beyond 10 days will increase oxygen requirements but will also provide a greater degree of waste stabilization. This may be necessary if storage occurs following aerobic treatment and odorous end products from anaerobic processes can result from remaining unstabilized wastes. It was not possible to determine a clear relationship between malodors generated from the stored sludge and the degree of stabilization in this study. It was observed that the nature of the odors generated during storage differed from those common to untreated, liquid poultry manure. The intensity of the malodors from the stored sludge was significantly lower and diffused rapidly. In contrast, untreated liquid poultry manure continues to be a source of odors for an extended period of time following field spreading. This comparison shows that aeration is effective in controlling odors following field spreading even if storage follows aeration.

If nitrification is desired, provision of an adequate SRT to maintain a nitrifying population will be the constraining factor in determining the minimum SRT. The increased SRT for nitrification, particularly at low temperature, will increase oxygen requirements to meet both the additional exerted carbonaceous oxygen demand and the nitrogenous demand. The end result will be an increased degree of stabilization as well as nitrification.

## NITROGEN

The decision to remove or conserve nitrogen from poultry wastes is directly related to the opportunities to recycle this element through crop production. Although animal production not accompanied by cropping activities has the most stringent nitrogen removal requirements, the Manorcrest system design identified the need for nitrogen removal when crop production is limited.

The potential for nitrogen removal is limited by the ammonification process which is a function of SRT (Figures 13 and 38). The degree of nitrogen removal via ammonia stripping in oxidation ditches was shown to be substantial when nitrification was inhibited by the lack of available oxygen. Therefore, it appears that inhibition of nitrification is not an effective method of nitrogen conservation in aeration systems for poultry wastes. In addition, the disadvantages of the odor of ammonia in the building in the case of an in-house oxidation ditch and the potential adverse environmental impact from the discharge of ammonia into the atmosphere should be recognized.

It is necessary to meet the total exerted carbonaceous and nitrogenous oxygen demand to achieve nitrification. Based upon the mass balance results, it was calculated that the total exerted oxygen demand was 514 gms $O_2$/1000 bird-hours. Oxygen transferred was 520 gms $O_2$/1000 bird-hours. This demonstrates the validity of the method used to calculate oxygen demand, Equation 8. Since the oxygen supply was equal to the demand, no residual dissolved oxygen should have been present in the mixed liquor. As shown in Figure 19, residual dissolved oxygen concentrations were minimal during this period.

The potential for nitrogen conservation by maintenance of an adequate residual dissolved oxygen concentration could not be evaluated due to opportunities for denitrification in the settling tanks. At the highest levels of oxygen transfer, oxygen transfer capacity was 142 and 153 percent of the total exerted demand based on calculations from the mass balance results. This indicated that residual dissolved oxygen concentrations should have been maintained. Dissolved oxygen measurements, (Figures 20 and 21) confirm this conclusion. However, results of pilot plant studies (20) have shown that a 30 percent loss of nitrogen via denitrification can occur even at high dissolved oxygen levels. It is necessary to examine the value of the nitrogen conserved in comparison to the additional equipment and energy costs to determine the feasibility of this approach.

The observed removal of nitrogen via nitrification-denitrification even at relatively long SRT's (Table 22) demonstrated that the addition of an organic carbon source such as methanol is unnecessary for denitrification with these wastes. In comparison, the addition of an organic carbon source is commonly required for denitrification of nitrified domestic and industrial wastes.

The observation of $NO_2$-N on the 14th day of operation of Ditch II, demonstrated that seeding is not necessary to introduce nitrifying organisms into these systems. However, nitrification patterns indicating inhibition were observed on several occasions (Figures 14 and 15). Un-ionized ammonia ($NH_3$) and un-ionized nitrous acid ($HNO_2$) could have been the inhibitory compounds. Inhibition of nitrification by these compounds in poultry and other wastewaters has been reported (55). Free ammonia concentrations from 0.1 to 150 mg/ℓ were noted to be inhibitory. Free ammonia inhibition to Nitrobacter occurred at concentrations lower than those that inhibited Nitrosomonas. The inhibitory range for free nitrous acid was 0.2 to 2.8 mg/ℓ.

During the first 14 days of operation, the free ammonia concentration reached a maximum of 21.3 mg/ℓ. This is well within the above inhibitory range. Complete inhibition did not occur. However, comparison of $NO_2$-N and $NO_3$-N concentrations indicates that the inhibition to Nitrobacter was greater than that to Nitrosomonas. With the accumulation of nitrite, free nitrous acid levels increased and reached a maximum of 2.2 mg/ℓ on day 42 which is also well witnin the suggested inhibitory range.

The accumulation of $NO_2$-N affected system performance in several ways. First, complete nitrification did not occur. Significant mixed liquor ammonia residuals remained (Figures 14 and 15). It was observed that residual dissolved oxygen levels increased with increased $NO_2$-N concentrations (Figure 20). This indicates a reduction in exerted oxygen demand as $NO_2$-N concentrations increased.

The results of this study demonstrates that it is not necessary to seed these systems in order to introduce nitrifying organisms. However, it may be desirable to prevent an initial ammonia accumulation and the resulting free ammonia inhibition. This would, in turn, prevent the free nitrous acid inhibition from developing.

## LIQUID-SOLIDS SEPARATION

The process design concepts of a controlled mixed liquor total solids concentration and SRT are dependent on the removal of residual solids. Continuous dilution does not appear practical and an effective mechanism for liquid-solid separation is required. This study examined three alternative approaches; gravitational settling, screening, and centrifugation.

### Gravitational Settling

It does not appear that the poor performance of the gravitational liquid solids separation system at Manorcrest is a true indicator of the potential of this approach. The zone settling velocity studies suggest that at MLTS concentrations below 11,000 mg/ℓ, aerated poultry wastes have good settling characteristics. Therefore, this approach should not be entirely discounted. However, it is clear that the clarification and storage functions should be separated to prevent solids flotation in the clarification unit due to gas production from denitrification and other anaerobic processes.

In order to access feasibility in terms of clarifier size requirements, preliminary surface area requirements based on the ZSV test were calculated. The design approach presented by Lawrence (56) which is based upon the batch flux method (57) was used. The clarifier surface area requirements were calculated to be 929 $cm^2$ (1 $ft^2$) per 1000 birds. The design conditions were as follows:

Mixed liquor total solids concentration - 8,000 mg/ℓ
Solids retention time - 15 days
Underflow solids concentration - 70,000 mg/ℓ
Flow through the clarifier - 2440 ℓ/day

This indicates that a large clarification unit would not be required and that surface area was not an independent limiting factor in the Manorcrest settling units.

Using the specified design conditions, sludge production was calculated to be 287 ℓ per 1000 birds per day (76 gal./1000 birds/day). The volume of sludge requiring ultimate disposal would be 104 ℓ per bird per year (28 gal./bird/yr). Assuming the use of a 9462 ℓ (2500 gal.) manure spreader and an estimated time requirement of 30 minutes per load for loading, transportation, and spreading, the estimated time required to dispose of the yearly sludge production from 1000 birds would be 5.5 hours per year.

Caution should be used in utilizing the zone settling velocity results reported here as a basis for design. Further investigation is warranted to confirm these preliminary results and evaluate the effects of variation in methods of treatment system operation before using the reported data for actual design.

### Screening and Centrifugation

The results of the screening tests indicate that this process has only limited potential for liquid-solids separation in aerated poultry wastes. The major problem is that the mixed liquor suspended solids are very small. The results of the 200 mesh screening test indicated that 60 to 80 percent of the suspended solids were less than 0.074 mm in diameter. Based upon sieve analyses of fresh poultry wastes, 49 percent of the manure solids were reported (58) to be finer than 0.074 mm. Therefore, it appears that aerobic treatment changes the particle size distribution in these wastes. This fact is important not only with respect to screening but also to gravitational settling and possibly other separation processes.

A possible application of screening would be as the first step before aeration where it would be desirable to handle coarse solids separately.

Another possibility would be removal of coarse solids following aeration in a batch system. This could increase the time period to reach a selected maximum mixed liquor total solids concentration and thus increase storage time by 15 to 30 percent.

The centrifuge test results (Table 24) indicate that this process is capable of a high degree of solids removal from oxidation ditch mixed liquor. Also, it results in a concentrated sludge which can reduce the volume of material requiring ultimate disposal in comparison to direct disposal of mixed liquor. The supernatant can be recycled back into the aeration systems. Production of thickened solids containing 16 percent total solids would reduce sludge volume to approximately that of the original raw waste. This best can be understood by considering the following example. Fresh poultry manure contains roughly 25 percent total solids. If biological solids destruction occurred without dilution for aeration, 36 percent total solids destruction would result in the reduction in total solids to 16 percent. This is without any dilution to increase volume. Therefore, following dilution for and solids destruction during aeration, removal of dilution water by centrifugation to attain a sludge total solids concentration of 16 percent would result in a waste volume equal to the original volume of the raw waste. This suggests that increased waste volume requiring ultimate disposal is not necessarily a characteristic of aeration. This would serve to overcome a commonly cited disadvantage of aeration systems; increase in volume of the waste material due to dilution.

The tests results suggest that the use of centrifugation for liquid-solids separation has significant potential. However, due to the limited extent of the testing, comment on the practicality of the process is not possible at this time. Factors such as cost and ease of operation need to be evaluated along with more detailed testing before the total potential of centrifugation can be realistically evaluated.

## SEDIMENT ACCUMULATION

The problem of sediment accumulation encountered in this study indicates that the Manorcrest oxidation ditch design was inadequate in the area of hydraulics. The observed reduction of mixed liquor velocity as sediment accumulation occurred decreased mixing which is important to the biological process. Although biological process failure due to inadequate mixing did not occur, neither ditch was allowed to operate over an extended time period at mixed liquor velocities approaching zero. If sediment removal to increase velocity had not occurred, it appears reasonable to assume that failure would occur due to inadequate mixing and dissolved oxygen transport. This indicates that there is an interdependence between process and physical design. In addition, sediment removal was a time consuming and labor intensive operation.

The cause of the sediment accumulation was inadequate initial mixed liquor velocity. The accumulation of some sediment was not unexpected in that oxygen transfer and not pumping capacity was the primary consideration in aerator sizing. However, the design calculations and initial velocity measurements for Ditch II compared favorably with the recommended minimum velocity for oxidation ditches of 0.38 m/sec (1.25 ft/sec) (21).

Sedimentation was a major problem in both ditches, but it had a greater adverse impact in Ditch II. Accumulations of sediment were greater and the secondary effects more pronounced in Ditch II even though Ditch I had lower mixed liquor velocities. The reason for this phenomenon is not clear although it appears to be related to the type of aeration unit. This was the only physical difference between the two ditches.

Although accumulation of some sediment was not totally unexpected, it was assumed that the accumulations would reach an equilibrium. It was theorized that as the sediments reduced the channel cross-sectional area, velocity would increase until scour occurred. In fact, the reverse occurred. As sediment accumulation increased, velocity decreased thereby causing more settling. This process continued until the velocity approached zero as was demonstrated on several occasions in Ditch II. Use of the Manning uniform equation for open channel flow, Equation 20, to describe flow in an oxidation ditch provides a possible explanation for the effect of the sediments on mixed liquor velocity.

$$V = \frac{1.486}{N} R^{2/3} S^{1/2} \qquad (20)$$

where $V$ = velocity

$N$ = coefficient of roughness

$R$ = hydraulic radius, cross-sectional area divided by the wetted perimeter

$S$ = slope

Assuming a constant pumping capacity and therefore a constant equivalent to the energy line slope, the equation predicts velocity will decrease as the coefficient of roughness increases and/or as the hydraulic radius decreases. Sediment accumulations caused both to occur. The accumulation of 25.4 cm (10 in.) of sediment as occurred in Ditch II during 1973-74 reduced the hydraulic radius by 41 percent. Assuming both S and N remained constant, it was calculated that the resultant velocity reduction would be 29 percent.

Several factors affect the coefficient of roughness in the Manning equation (59). Included are surface roughness and channel irregularity. Surface roughness is a function of the shape and size of the grains of material forming the wetted perimeter. A significant difference should not exist between concrete and poultry manure solids. The sediment accumulations did significantly increase channel irregularity as shown in Figures 30 through 33. Irregularity can increase the value of N as much as 0.02 above the value for a smooth channel (59). Assuming an initial value of N of 0.016 for a concrete channel and an increase of 0.02 for irregularity, the effect of the increase coefficient of roughness and decreased hydraulic radius was calculated for Ditch II. The results of this calculation predicted that the initial velocity of 0.38 m/sec (1.25 ft/sec) would decrease to 0.12 m/sec (0.39 ft/sec) which agrees reasonably well with observed performance. The problem with the original theory, which assumed that scour would cause sediment accumulations to reach an equilibrium, lies in the failure to recognize that friction losses are not constant.

It is clear that sedimentation in oxidation ditches should be prevented. Therefore, mixed liquor design velocities in these systems should equal or exceed the scour velocity necessary to keep the heaviest manure particles in suspension. The scour velocity for poultry manure was calculated to be 0.53 m/sec (1.74 ft/sec) using the following relationship:

$$V_H = \left[\frac{8k(s-1)gd}{f}\right]^{1/2} \tag{21}$$

where $V_H$ = horizontal velocity that will produce scour

$s$ = specific gravity of particles

$d$ = diameter of particles

$k$ = constant dependent on type of material being scoured

$f$ = Darcy - Weisbach friction factor

The values used in this calculation and their sources are as follows:

$s$ = 2 gms/cm$^3$ (58)

$d$ = 1.19 mm maximum (58)

$k = 0.06$ (60)
$f = 0.02$ (60)

This indicates that the currently recommended minimum design velocity of 0.38 m/sec (1.25 ft/sec) is not adequate for poultry wastes.

This conclusion has a significant impact on the design of these systems. Analysis of results has shown that the Thrive rotor's oxygen transfer capacity was excessive in comparison to the combined carbonaceous and nitrogenous oxygen demand. However, the results of this analysis also indicate that the unit was under-sized in terms of pumping capacity. Two methods of increasing pumping capacity exist. They are increasing the size of the aeration unit or using a supplemental pumping device. Both solutions will increase capital and operating costs and may make aeration economically unattractive.

An alternative solution may lie in improvement of the hydraulic design of oxidation ditch channels to reduce friction losses, as suggested by Simons (61). This would result in velocity increases without increasing energy input. Opportunities exist to reduce friction losses through improvement of cross-section channel geometry and the geometry of the semi-circular curves connecting the two linear channels. As can be seen in the Manning equation, increasing the hydraulic radius will increase velocity. This can be achieved by decreasing the wetted perimeter in relation to the liquid cross-sectional area. However, the potential for increasing velocity by this approach is small.

Based upon a comparison of velocity in Manorcrest Ditch II and an oxidation ditch discussed by Windt, et al. (62), it appears that significant increases in velocity at a fixed energy input can be achieved by increasing the radius of curvature of the semi-circular connecting channels. Details of both ditches are presented in Table 34. Although volume per

Table 34. COMPARISON OF THE PHYSICAL DETAILS OF MANORCREST DITCH II AND AN OXIDATION DITCH DISCUSSED BY WINDT, et al

| | Manorcrest Ditch II | Oxidation Ditch Discussed by Windt, et al. (62) |
|---|---|---|
| Length of straight channel section | 39.6 m | 27.7 m |
| Channel width | 2.3 m | 2.4 m |
| Liquid depth | 51 cm | 56 cm |
| Radius of curvature of semi-circular sections | 1.6 m | 3.8 m |
| Volume | 106 $m^3$ | 93.5 $m^3$ |
| Rotor | Thrive H-805 | Thrive H-805 |
| Rotor length | 1.7 m | 1.7 m |
| Immersion depth | 13 cm | 15 cm |
| Volume per unit rotor length | 62.4 | 55 |
| Velocity | 0.38 m/sec | 0.61 m/sec |

unit length of rotor and therefore energy input was less in the Manorcrest ditch, it does not appear that this factor alone is responsible for the significant difference in liquid velocity.

The greatest geometrical difference between the two ditches was the radius of curvature of the semi-circular sections. In a discussion of energy loss resulting from curve resistance, Chow (59) states that the coefficient of curve resistance, $f_c$, is a function of several factors. They are:

$R_n$ = Reynolds number
$y/b$ = ratio of liquid depth to channel width
$\alpha/180°$ = ratio of angle of curvature to 180°
$r_c/b$ = ratio of radius of curvature to channel width

Assuming a constant velocity and therefore Reynolds number, the only parameter that varies significantly between the two ditches is $r_c/b$. The value of this ratio is 0.7 for the Manorcrest ditch and 1.6 for the oxidation ditch discussed by Windt. The effect of this difference on $f_c$ can not be calculated. However, experiment results reported by Shukry (63) showed a decrease in $f_c$ from 0.91 to 0.32 when $r_c/b$ increased from 0.5 to 1.0. Values of the other parameters in the study where:

$R = 7.5 \times 10^{-4}$
$y/b = 1$
$\alpha/180° = 0.5$

While this result does not directly apply to the comparison under consideration, it does illustrate the effect of the radius of curvature in a nonlinear channel on $f_c$. The effect of $f_c$ on energy loss due to curve resistance in terms of velocity head can be expressed as follows:

$$h_f = f_c \frac{V^2}{2g} \qquad (22)$$

where $h_f$ = velocity head
$V$ = mean velocity in the section
$g$ = acceleration due to gravity

It can be seen that as $f_c$ increases, $h_f$ to maintain a constant velocity also increases.

Unfortunately, precise relationships concerning flow in nonlinear open channels have not been defined. However, it appears that velocity in oxidation ditches can be increased without increasing energy input by improving hydraulic design. This suggests that the current practice of adapting oxidation ditches to animal housing patterns such as placing channels below cages may need revision.

## FOAMING AND EXCESS WATER

As indicated in the results section, foaming problems of a nuisance nature were encountered in this study. The causes of the foaming are not clear. Inadequate oxygen supply resulting in anaerobic conditions is often cited as the cause of foam. However, foaming problems did not occur in Ditch I, which was the minimally aerated system, but rather in Ditch II where residual dissolved oxygen concentrations were maintained.

Accumulated sediments have also been suggested as a causative agent of foaming in a study of aerobic treatment of swine wastes (47). However, sediment accumulations were present in both Manorcrest ditches but foaming only occurred in Ditch II. Based upon the observations during this study and from previous experience, it appears that there are several factors which will cause foaming. However, relationships are not clear. With the exception of an overloaded condition, it appears that adequate velocity to maintain continuous foam movement can prevent foam from becoming a problem.

In a pilot plant study, it was reported that no overflow occurred from an oxidation ditch treating poultry wastes (6). In this study, it was necessary to add water to offset evaporative losses. It appears that the same situation should occur under commercial conditions if leakage from the bird watering system is eliminated. This can be accomplished through the use of a trough type watering system. Water addition via manure is low and was calculated to be approximately 79 ℓ per 1000 birds per day (21 gal per 1000 birds per day) at Manorcrest. Evaporative losses should offset the quantity of water added as manure.

## ECONOMIC IMPACT

The practicality of aeration as a poultry waste management tool will depend heavily on economic impact. Since the price the producer receives for eggs is determined by the market forces of supply and demand, there is not opportunity to pass the cost of pollution control measures. The economic impact of any waste management system on net income is a logical criteria for the economic assessment of that system. However, a 1973 survey (64) of 40 New York State poultry farms showed that labor and management incomes varied widely. Income ranged from minus values to over $30,000 per operator. Similar variations were reported in 1971 and 1972 (65,66). Differences in management skills among producers appear to be the major factor responsible for this variability.

As an alternative, capital investment and production costs were used as baselines for economic assessment. This procedure allows determination of economic impact in terms of efficient production resulting from skillful management. Egg production costs in New York State for the years 1971-73 are presented in Table 35. The values noted are average values reported for New York State except for feed costs. Feed costs were based on 1.91 kg (4.2 lbs) of feed per dozen eggs and 20 dozen eggs marketed per hen year. The effect of good management is reflected in the selected feed conversion efficiency and production values which are above average for the three years evaluated.

Table 35. NEW YORK STATE EGG PRODUCTION COSTS (64,65,66)

| Cost /hen-year | 1973 | 1972 | 1971 |
|---|---|---|---|
| Return to capital @9% | $ .67 | $ .56 | $ .62 |
| Labor* | .94 | .87 | 1.05 |
| Feed | 5.12 | 3.23 | 3.56 |
| Hen** | 1.75 | 1.75 | 1.75 |
| Building repairs | .03 | .04 | .04 |
| Electricity | .11 | .10 | .09 |
| Taxes | .07 | .06 | .07 |
| Insurance | .11 | .09 | .09 |
| Total | $8.80 | $6.70 | $7.27 |
| Production cost/ dozen eggs | 0.44 | 0.335 | 0.364 |

* Includes operator's labor

**Estimated cost $2.00/bird, less salvage value of $.25/bird

The capital costs of the Manorcrest aeration systems, Table 30, are high in comparison to those previously reported for another application of oxidation ditches for poultry waste treatment. That system, Houghton's, was also evaluated by personnel from the Cornell Agricultural Waste Management Program (16). An itemized comparison of the capital costs for both systems per 1000 birds is presented in Table 36.

As shown, the major factor in the high capital cost of the Manorcrest systems is the construction cost for conversion of the four manure collection pits into two oxidation ditches. One factor contributing to the higher costs at Manorcrest was the smaller number of birds, 8,000, in comparison to the 15,000 birds at the Houghton Farm. Both conversions were similar requiring the connection of four manure collection pits to form two oxidation ditches. Since the Houghton system served more birds, the result was a lower unit cost.

However, this does not account for the total difference. Another factor was the decision to place the connecting channels beyond the ends of the cage rows at Manorcrest which increased construction costs. This placed these channels in the service alleys at each end of the cage rows and necessitated the construction of a floor system capable of supporting workers and feed and egg carts over the connecting channels. Conversely, the connecting channels were placed under the cages at the Houghton Farm.

The use of precast concrete settling and storage tanks also increased the capital cost of the Manorcrest systems. Estimation of costs for alternative approaches to liquid-solid separation and storage awaits the results of more detail investigation into this area.

The energy costs for aeration determined in this study, Table 31, were significantly lower than those previously reported. Power costs of two to four cents per dozen eggs have been reported for a pilot plant scale oxidation ditch (67), and one cent per dozen for a full scale, 15,000 bird, oxidation ditch system (16). The impact of energy costs

### Table 36. COMPARISON OF CAPITAL COSTS PER 1,000 BIRDS, MANORCREST FARMS AND HOUGHTON'S POULTRY FARM

| | Manorcrest | | Houghton |
|---|---|---|---|
| | Ditch I | Ditch II | |
| Construction | $1,092 | $1,092 | $187 |
| Settling tanks | 380 | 380 | --- |
| Aeration units | 375 | 530 | 480 |
| | $1,847 | $2,002 | $667 |
| Annual capital cost per 1,000 hens | $ 222 | $ 248 | $ 95 |
| Annual capital cost per dozen eggs | .0111 | .0124 | .0047 |

for the four levels of oxygen transfer evaluated in this study on production costs are presented in Table 37. For three years 1971-73, energy costs of aeration for odor control would have increased production costs by a maximum of one percent. Even at the highest level of oxygen transfer where transfer capacity exceeded calculated total demand by approximately 45 percent, the maximum increase in production costs would have been only two percent.

The total economic impact of the use of aeration for the different designs and modes of operation on egg production costs, for the years 1971-73, are summarized in Table 38. The increased total cost of aeration for odor control never exceeded 5 percent even with the high capital costs characteristic of this study. The cost of electricity was $.0201 per kwhr for this study and may differ elsewhere.

This study has demonstrated that process design based on fundamental concepts of the biological waste treatment process and oxygen transfer can reduce energy costs for aeration. This point is illustrated by comparison of the energy costs between the Houghton system and Manorcrest. The design and operation of the Houghton system was based on empirical parameters where as a more fundamental approach was used for Manorcrest. Energy cost per dozen eggs for odor control at Houghton's was reported to be $0.0100 (16) in comparison to $0.0056 per dozen eggs at Manorcrest (Table 31).

In evaluating these energy costs, it is important to realize that energy costs are also a function of the aerator oxygen transfer efficiency. Both aeration units in this study delivered approximately 1500 gms $O_2$ per kwhr (2.5 lbs $O_2$ per hp-hr). Other types of surface aeration equipment with higher efficiencies, 2400 gms $O_2$ per kwhr (4 lbs $O_2$ per hp-hr) are available (60). A turbine aeration system evaluated in a pilot plant scale study of poultry wastes has been reported to have an oxygen transfer efficiency of approximately 3000 gms $O_2$ per kwhr (5 lbs $O_2$ per

### Table 37. EFFECT OF POWER COSTS FOR AEROBIC STABILIZATION ON EGG PRODUCTION COSTS

| Level of Oxygen Transfer Capacity, gms $O_2$/1000 bird-hrs. | Degree of Stabilization | Percentage Increase In Egg Production Costs | | |
|---|---|---|---|---|
| | | 1973 | 1972 | 1971 |
| 351 | Odor control | 0.8 | 1.0 | 0.9 |
| 520 | Nitrification-denitrification | 1.1 | 1.4 | 1.3 |
| 790 & 815 | Potential nitrogen conservation | 1.6 | 2.0 | 1.8 |

### Table 38. EFFECT OF TOTAL COSTS FOR AEROBIC STABILIZATION ON EGG PRODUCTION COSTS

| Level of Oxygen Transfer Capacity gms $O_2$/1000 bird-hrs. | Degree of Stabilization | Percentage Increase In Egg Production Costs | | |
|---|---|---|---|---|
| | | 1973 | 1972 | 1971 |
| 351 | Odor control | 3.8 | 5.0 | 4.6 |
| 520 | Nitrification-denitrification | 4.1 | 5.3 | 4.9 |
| 790 & 815 | Potential nitrogen conservation | 4.9 | 6.4 | 5.9 |

hp-hr) (42). The use of more efficient aeration equipment would reduce operating costs but may require a system different from the oxidation ditch.

The differences in capital costs between Manorcrest and the Houghton farm suggest that opportunities for cost reduction are available. The location of the semi-circular connecting channels beyond the end of the cage rows in the service alleys at Manorcrest necessitated excavation and construction of a floor system which increased construction costs. In contrast, these channels were placed under the cages and reduced construction costs for the Houghton system. Use of an earthen lagoon in place of precast concrete tanks would also reduce capital costs. Realization of these lower capital costs along with the low power costs demonstrated in this study should result in further improvements in what appear to be reasonable costs.

# REFERENCES

1. Jasper, A.W. Some Statistical Highlights of the Poultry Industry. American Farm Bureau Federation. 1973.

2. The College of Agriculture and Environmental Sciences, Rutgers University. Poultry Manure Disposal by Plow Furrow Cover. Final Report Grant EC-00254-03, U.S. Environmental Protection Agency. 1972. 108 p.

3. Bartlett, H.D. and L.F. Marriot. Subsurface Disposal of Liquid Manure. In: Livestock Waste Management and Pollution Abatement. ASAE. St. Joseph, Michigan. 1971. p. 258-260.

4. Loehr, R.C., T.B.S. Prakasam, E.G. Srinath, T.W. Scott and T.W. Batemen. Design Parameters for Animal Waste Treatment Systems -- Nitrogen Control. Environmental Protection Technology Series Report. U.S. Environmental Protection Agency. In press. 142 p.

5. Vickers, A.F. and E.J. Genetelli. Design Parameters for the Stabilization of Highly Organic Manure Slurries by Aeration. Proc. Agric. Waste Management Conference, Cornell University, Ithaca, New York. 1969. p. 37-49.

6. Loehr, R.C., D.F. Anderson, and A.C. Anthonisen. An Oxidation Ditch for the Handling and Treatment of Poultry Wastes. In: Livestock Waste Management and Pollution Abatement. ASAE. St. Joseph, Michigan. 1971. p. 209-212.

7. Federal Register. Effluent Guidelines Standards, Feedlots Point Source Category. Washington, D.C. 39:5704-5708. February, 1974.

8. Sobel, A.T. Physical Properties of Animal Manure Associated with Handling. In: Management of Farm Animal Wastes. ASAE. St. Joseph, Michigan. 1966. p. 27-32.

9. Stewart, T.A. and R. McIlwain. Aerobic Storage of Poultry Manure. In: Livestock Waste Management and Pollution Abatement. ASAE. St. Joseph, Michigan. 1971. p. 261-262.

10. Hashimoto, A.G. Characterization of White Leghorn Manure. Proc. Agric. Waste Management Conference. Cornell Univeristy, Ithaca, New York. 1974. p. 141-152.

11. Prakasam, T.B.S., R.C. Loehr, P.Y. Yang, T.W. Scott, and T.W. Batemen. Design Parameters for Animal Waste Treatment Systems. Environmental Protection Technology Series Report No. EPA 660/2-74-063. Washington, D.C. 1974. 218 p.

12. Nieswand, S.P. An Evaluation of a Full-Scale In-House Oxidation Ditch for Poultry Waste. Unpublished M.S. Thesis, Cornell University, Ithaca, New York. 1974. 140 p.

13. Development Document for Effluent Limitation Guidelines and Standards of Performance for New Sources for the Feedlots Point Source Category. U.S. Environmental Protection Agency, Washington, D.C., February, 1974. (U.S. Government Printing Office Stock No. 5501-00842).

14. Morris, G.R., Unpublished data. Cornell University Agricultural Waste Management Program. 1975.

15. Converse, J.C., D.L. Day, J.T. Pfeffer and B.A. Jones, Jr. Aeration with ORP Control to Suppress Odors Emitted from Liquid Swine Manure Systems. In: Livestock Waste Management and Pollution Abatement. ASAE. St. Joseph, Michigan. 1971. p. 267-271.

16. Martin, J.H., R.C. Loehr, A.C. Anthonisen, and S.P. Nieswand. Aerobic Treatment of Poultry Wastes. ASAE Paper No. 74-4029. St. Joseph, Michigan. 1974. 35 p.

17. Holmes, B.J. Effect of Drying on the Losses of Nitrogen and Total Solids from Poultry Manure. Unpublished M.S. Thesis, Cornell University. 1973. 97 p.

18. Hashimoto, A.G. Aeration Under Caged Laying Hens. ASAE Paper No. NAR-71-428. St. Joseph, Michigan. 15:1119-1123, 1972.

19. Dunn, G.G. and Robinson, J.B. Nitrogen Losses through Denitrification and Other Changes in Continuously Aerated Poultry Manure. Proc. Agric. Waste Management Conference, Cornell University, Ithaca, New York. 1972. pp. 545-554.

20. Prakasam, T.B.S., E.G. Srinath, A.C. Anthonisen, J.H. Martin, Jr., and R.C. Loehr. Approaches for the Control of Nitrogen with an Oxidation Ditch. Proc. Agric. Waste Management Conference, Cornell University, Ithaca, New York. 1974. p. 421-435.

21. Jones, D.D., D.L. Day, and A.C. Dale. Aerobic Treatment of Livestock Wastes. Bulletin 737, University of Illinois at Urbana-Champaign. 1970. 55 p.

22. Agricultural Engineers Digest. Oxidation Ditch for Treating Hog Wastes. AED-14, Midwest Plan Service, Iowa State University. Ames, Iowa. 1970.

23. Canada Department of Agriculture. Canada Animal Waste Management Guide. Publication 1534. Ottawa, Ontario. 1974.

24. Fair, G.M. and J.C. Geyer. *Elements of Water Supply and Waste-Water Disposal*. John Wiley and Sons, New York 1958. p. 418-420.

25. Owens, J.D., M.R. Evans, F.E. Thuder, R. Hissett, and S. Baines. Aerobic Treatment of Piggery Wastes. Water Research 7:1745-1766, 1973.

26. Monod, J. The Growth of Bacterial Cultures. Ann. Rev. Microbiology. 3:371-394, 1949.

27. Lawrence, A.W. and P.L. McCarty. Unified Basis for Biological Treatment Design and Operation. J. Sanitary Eng. Div., ASCE, 96:757-778, 1970.

28. Stensel, H.D. and G.L. Shell. Two Methods of Biological Treatment Design. J. Water Poll. Control Fed. 46:271-283, 1974.

29. Woods, J.L. and J.R. O'Callaghan. Mathematical Modelling of Animal Waste Treatment. J. Agric. Eng. Res. 19:245-258, 1974.

30. Loehr, R.C., T.B.S. Prakasam, E.G. Srinath, and Y.D. Joo. Development and Demonstration of Nutrient Removal From Animal Wastes. Environmental Protection Technology Series Report No. EPA-R2-73-095, U.S. Environmental Protection Agency. 1973. 340 p.

31. Downing, A.L., H.A. Painter, and G. Knowles. Nitrification in the Activated Sludge Process. Journal Institute of Sewage Purification. Part 2. 1964. p. 130-158.

32. Loehr, R.C. Agricultural Waste Management. New York, Academic Press, 1974. 242 p.

33. Cullen, E.J. and J.F. Davidson. The Effect of Surface Active Agents on the Rate of Adsorption of Carbon Dioxide by Water. Chemical Engineering Science. 6:2, 49-50, 1956.

34. Downing, A.L. and A.G. Boon. Oxygen Transfer in the Activated Sludge Process. Air and Water Pollution 5:131-148, 1963.

35. O'Connor, D.J. Effects of Surface Active Agents on Reaeration. Air and Water Pollution 5:123-130, 1963.

36. Gaden, E.L., Jr. Aeration and Oxygen Transport in Biological Systems - Basic Considerations. In: Biological Treatment of Sewage and Industrial Wastes. New York, Reinhold Publishing Corp., 1956. p. 172.

37. Baker, D.R., R.C. Loehr, and A.C. Anthonisen. Oxygen Transfer at High Solids Concentrations. J. Environ. Eng. Div., ASCE. 101:759-774. 1975.

38. Gameson, A.L. and K.G. Robertson. The Solubility of Oxygen in Pure Water and Sea Water. Journal of Applied Chemistry. 5:502, 1955.

39. Water Pollution Control Federation. Aeration in Wastewater Treatment - Manual of Practice No. 5. Washington, D.C. 1970.

40. Anderson, D.R. and M. Hurd. Study of Complete Mixing Activated Sludge. J. Water Poll. Control Fed. 43:422-432, 1971.

41. Pfeffer, J.T., F.C. Hart, and L.A. Schmid. Field Evaluation of Aerators in Activated Sludge Systems. Proc. 23rd Industrial Waste Conference, Purdue University, 183-194, 1968.

42. Hashimoto, A.G. and Y.R. Chen. Turbine-Air Aeration System for Poultry Wastes. In: Managing Livestock Wastes. ASAE. St. Joseph, Michigan. 1975. p. 530-534.

43. Stratton, F.E. and P.L. McCarty. Prediction of Nitrification Effects on the Dissolved Oxygen Balance of Streams. Environmental Science and Technology. 1:405-410, 1972.

44. Terashima, S., K. Koyama, and Y. Mazara. In: Biological Sewage Treatment in a Cold Climate Area. (R.S. Murphy and D. Nyguist, eds.). College, Alaska. EPA Report 16100 EXH. University of Alaska, 1971. p. 263-385.

45. Fair, G.M. and J.C. Geyer. Elements of Water Supply and Wastewater Disposal. John Wiley and Sons, New York, 1958. p. 329.

46. Jones, D.D., D.L. Day, and J.C. Converse. Oxygenation Capacities of Oxidation Ditch Rotors for Confinement Livestock Buildings. In: Proc. of the 24th Annual Purdue Industrial Waste Conference, Lafayette, Indiana, Purdue University, 1969. p. 191-208.

47. Martin, J.H. Unpublished Data. Cornell University Agricultural Waste Management Program. 1972.

48. McKinney, R.E. and R. Bella. Water Quality Changes in Confined Hog Waste Treatment. Project Report: Kansas Water Resources Research Institute. University of Kansas, Lawrence, Kansas. 1967. 88 p.

49. American Public Health Association. Standard Methods for the Examination of Water and Wastewater. 13th ed. New York, 1971.

50. McKenzie, H.A. and H.S. Wallace. The Kjeldahl Determination of Nitrogen: A Critical Study of Digestion Conditions, Temperature, Catalyst, and Oxidizing Agent. Aust. J. Chem (Sidney) 7:55-71. 1954.

51. Prakasam, T.B.S., E.G. Srinath, P.Y. Yang, and R.C. Loehr. Analyzing Physical and Chemical Properties of Liquid Waste. In: Standardizing Properties and Analytical Methods Related to Animal Waste Research. ASAE. St. Joseph, Michigan. 1975. p. 114-166.

52. Montgomery, H.A.C. and J.F. Dymock. The Determination of Nitrite in Water. Analyst 86:414-416. 1961.

53. Jeris, J.S. A Rapid COD Test. Water and Wastes Engineering. 4:89-91, 1967.

54. Srinath, E.G., R.C. Loehr, and T.B.S. Prakasam. Nitrifying Organism Concentrations and Activity. Accepted for Publication. J. Environ. Eng. Div., ASCE.

55. Anthonisen, A.C., R.C. Loehr, T.B.S. Prakasam, and E.G. Srinath. Inhibition of Nitrification by Ammonia and Nitrous Acid. (Presented at the 47th Annual Conf., Water Pollution Control Federation, Denver, Colorado, October 1974) and accepted for publication by the J. Water Poll. Control Fed.

56. Lawrence, A.W. Modeling and Simulation of Slurry Biological Reactors. In: Mathematical Modeling and Environmental Engineering. Association of Environmental Engineering Professors. 8th Annual Workshop, Nassau Bahamas. 1972. p. 216-255.

57. Dick, R.I. Role of Activated Sludge Final Settling Tanks. J. Sanitary Eng. Div., ASCE 96:423-436, 1970.

58. Sobel, A.T. Physical Properties of Animal Manures Associated with Handling. In: Farm Animal Wastes. ASAE. St. Joseph, Michigan. 1966. p. 27-32.

59. Chow, V.T. Open-Channel Hydraulics. New York, McGraw-Hill Book Company, 1959. 680 p.

60. Metcalf and Eddy, Inc. Wastewater Engineering. New York, McGraw-Hill Book Company, 1972. 782 p.

61. Simons, D., D.D. Jones, and A.C. Dale. Oxidation Ditch Analysis and Field Evaluation of the Aerob-A-Jet. Proc. Agricultural Waste Management Conference, Cornell University, Ithaca, New York. 1974. p. 436-454.

62. Windt, T.A., N.R. Bulley, and L.M. Staley. Design, Installation, and Biological Assessment of a Pasveer Oxidation Ditch on a Large British Columbia Swine Farm. In: Livestock Waste Management and Pollution Abatement. ASAE. St. Joseph, Michigan. 1971. p. 213-216.

63. Shukry, A. Flow Around Bonds in an Open Flume. Transactions, ASCE. 115:751-779, 1950.

64. Bratton, C.A., and G.H. Thacker. 1973 Poultry Farm Business Summary. Dept. of Agricultural Economics, Cornell University, Ithaca, New York. 1974. 34 p.

65. Bratton, C.A., and G.H. Thacker. 1972 Poultry Farm Business Summary. Dept. of Agricultural Economics, Cornell University, Ithaca, New York. 1973. 34 p.

66. Bratton, C.A., and G.H. Thacker. 1971 Poultry Farm Business Summary. Dept. of Agricultural Economics, Cornell University, Ithaca, New York. 1972. 34 p.

67. Ludington, D.C., A.T. Sobel, R.C. Loehr, and A.G. Hashimoto. Pilot Plant Comparison of Liquid and Dry Waste Management Systems for Poultry Manure. Proc. Agric. Waste Management Conf., Cornell University, Ithaca, New York. 1972. p. 569-580.

# SECTION IX

# APPENDICES

| FIGURE | TITLE | PAGE |
|---|---|---|
| A1 | Motor performance data for the brush aeration unit | 147 |
| A2 | Motor performance data for the Thrive Center Aeration Unit | 148 |
| A3 | Motor performance data for the propeller drive unit, 115 rpm | 149 |
| A4 | Motor performance data for the propeller drive unit, 230 rpm | 150 |

| TABLE | TITLE | PAGE |
|---|---|---|
| A1 | Relationships Between SRT and Treatment Effeciencies | 151 |

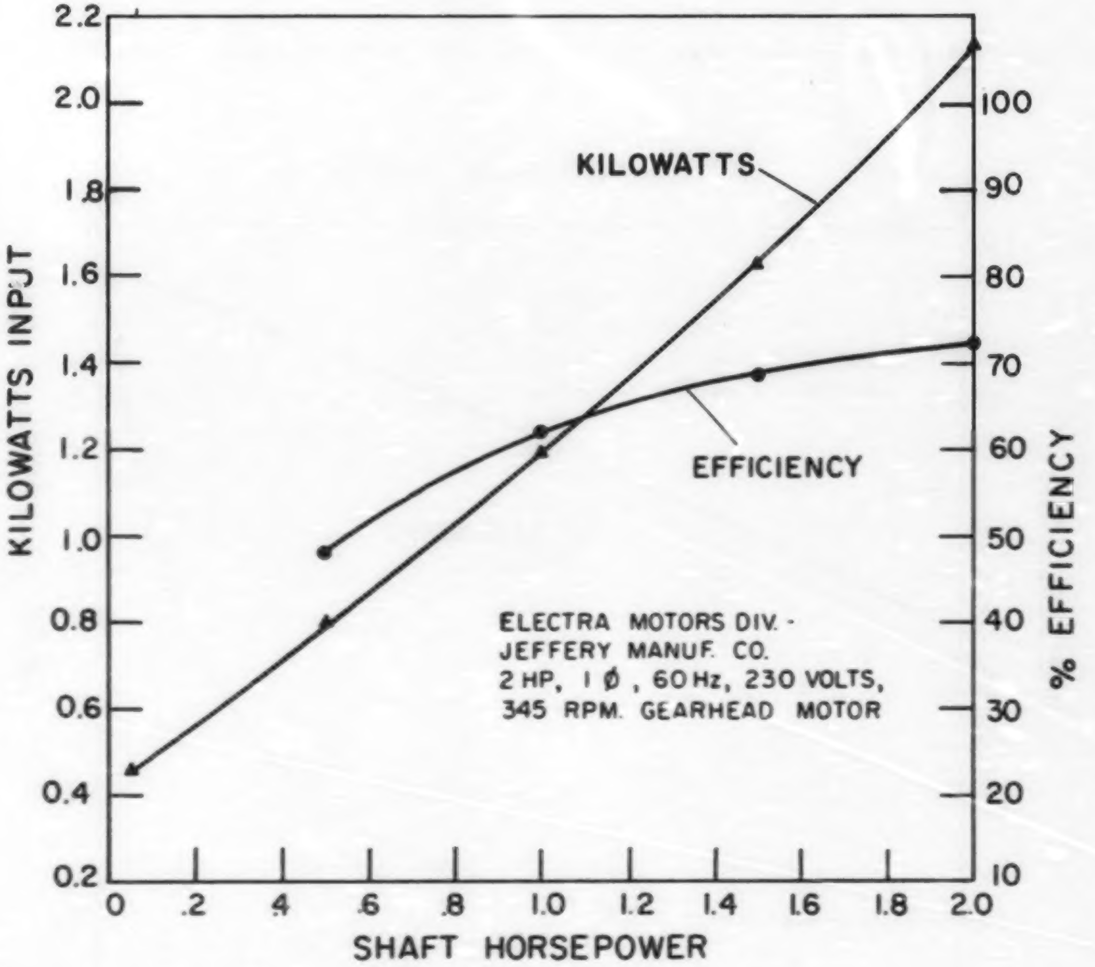


Figure A1. Motor Performance data for the brush aeration unit

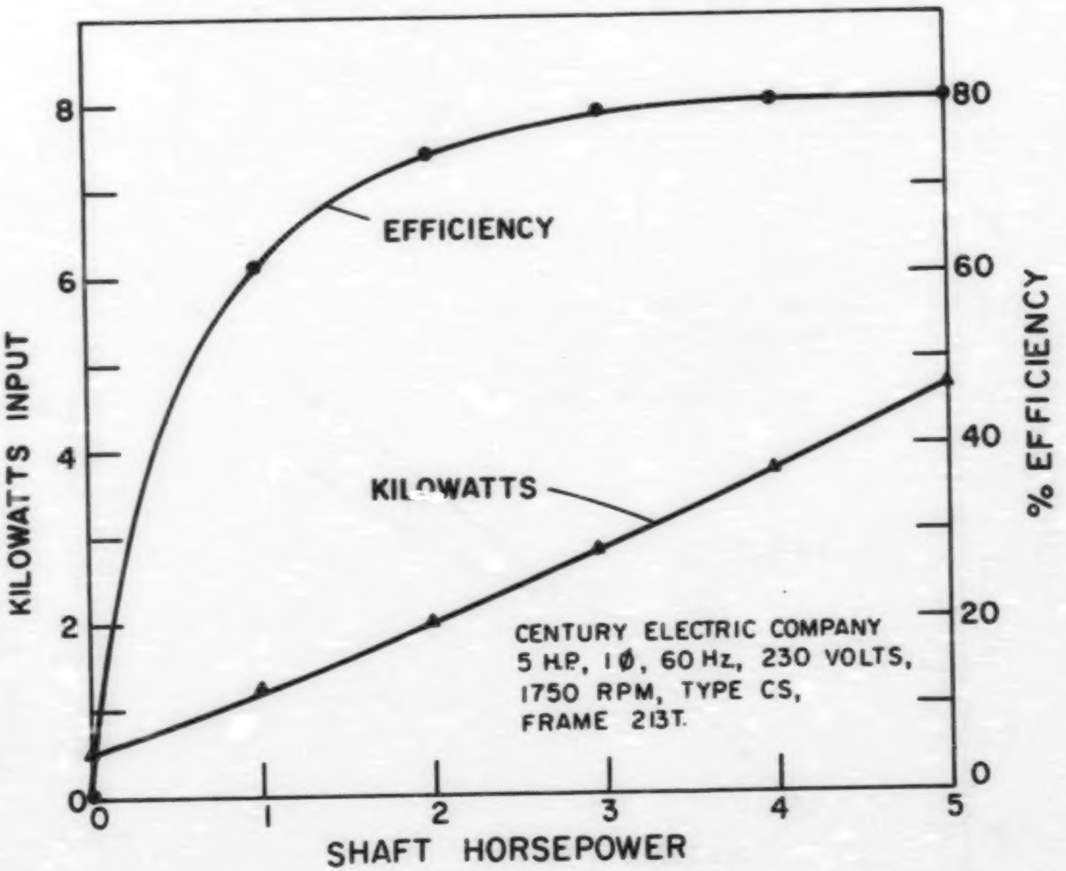


Figure A2. Motor performance data for the Thrive Center Aeration Unit

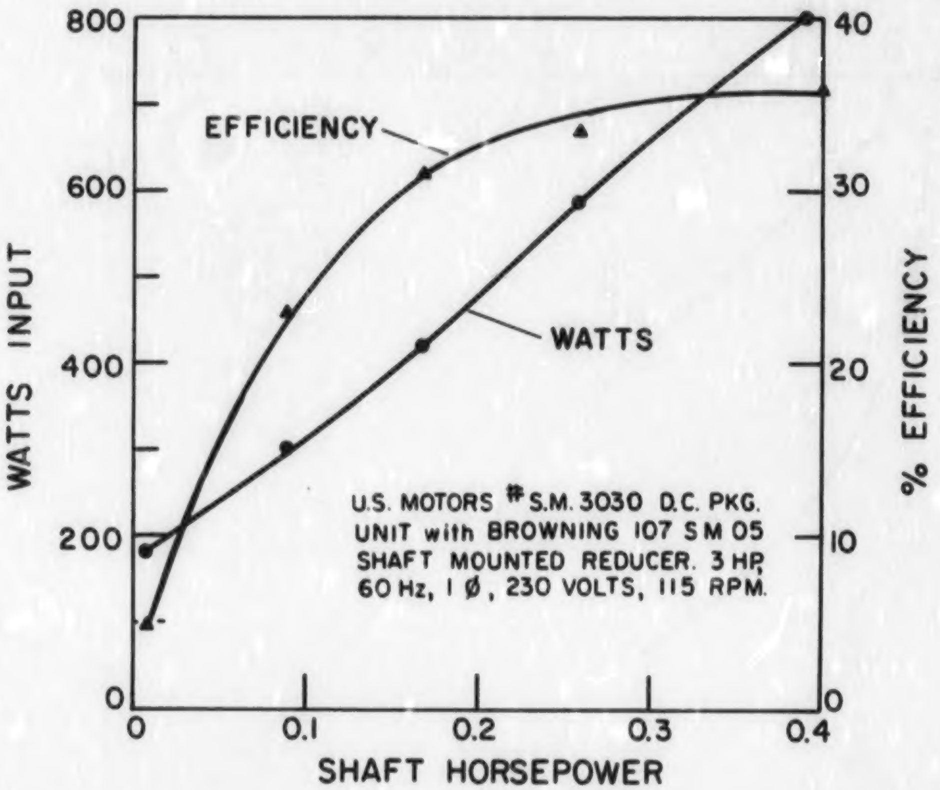


Figure A3. Motor performance data for the propeller drive unit, 115 rpm

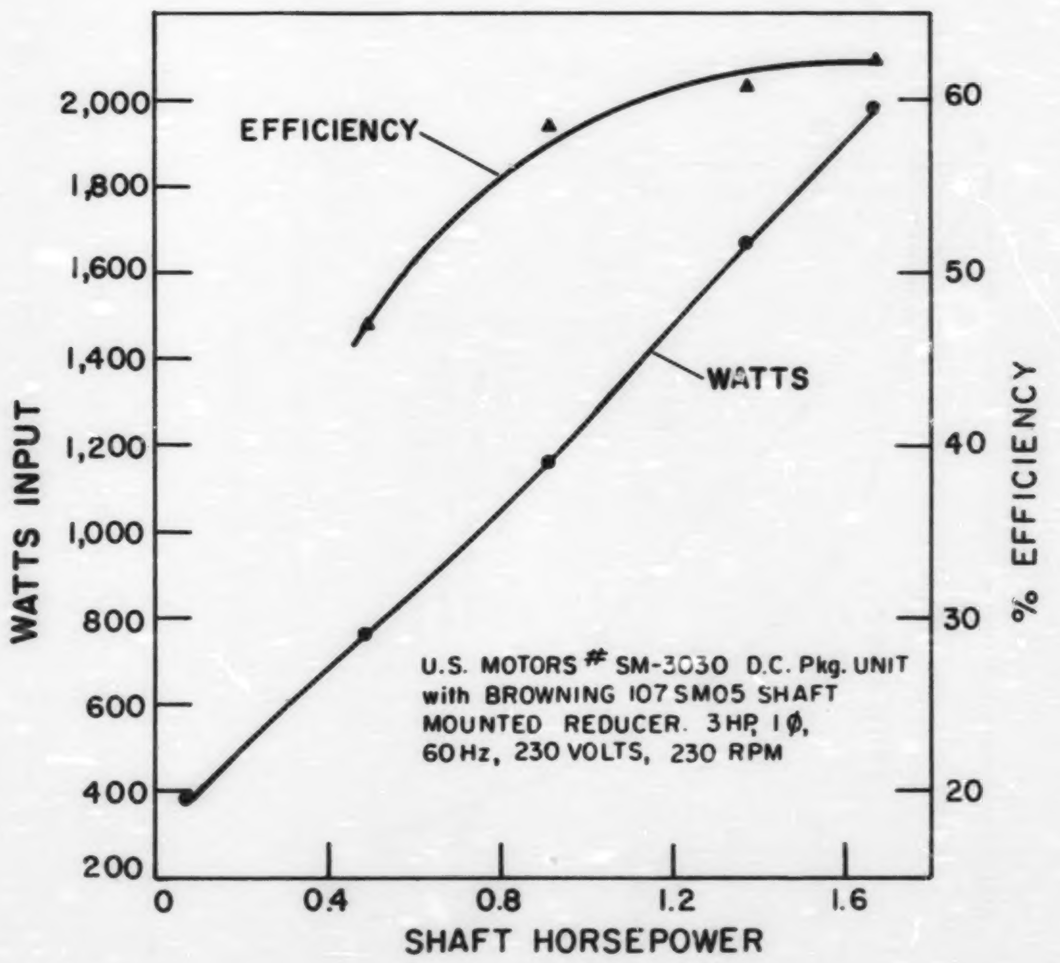


Figure A4. Motor performance data for the propeller drive unit, 230 rpm

Table A1. RELATIONSHIPS BETWEEN SRT AND TREATMENT EFFICIENCIES

| Ditch No. | Length of Equilibrium Period (Days) | Average Total Solids Concentration, mg/ℓ | SRT Days | Removal Efficiencies (%) | | | |
|---|---|---|---|---|---|---|---|
| | | | | Solids | | | |
| | | | | Total | Volatile | COD | Organic Nitrogen |
| I | 25 | 13,760 | 10.5 | 26.5 | 37.5 | 22.4 | 49.0 |
| I | 56 | 9,960 | 15.0 | 38.9 | 50.8 | 32.9 | 55.0 |
| II | 14 | 21,570 | 18.0 | 33.0 | 46.5 | 36.2 | 58.5 |
| I | 56 | 13,550 | 21.0 | 37.9 | 49.1 | 31.2 | 60.4 |
| II | 34 | 19,800 | 27.0 | 35.4 | 47.7 | 31.4 | 64.7 |
| II | 36 | 23,830 | 36.5 | 40.8 | 54.3 | 35.0 | 63.3 |

## TECHNICAL REPORT DATA

*(Please read Instructions on the reverse before completing)*

| | | |
|---|---|---|
| 1. REPORT NO.<br>EPA-600/2-76-186 | 2. | 3. RECIPIENT'S ACCESSION NO. |
| 4. TITLE AND SUBTITLE<br>Demonstration of Aeration Systems for Poultry Wastes | | 5. REPORT DATE<br>October 1976 (Issuing Date)<br>6. PERFORMING ORGANIZATION CODE |
| 7. AUTHOR(S)<br>J.H. Martin, Jr. and R.C. Loehr, Cornell University, Ithaca, New York 14853 | | 8. PERFORMING ORGANIZATION REPORT NO. |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS<br>Manorcrest Farms<br>5322 Munro Road<br>Camillus, NY 13031 | | 10. PROGRAM ELEMENT NO.<br>1HB617<br>11. CONTRACT/GRANT NO.<br>S800863 |
| 12. SPONSORING AGENCY NAME AND ADDRESS<br>Environmental Research Laboratory - Athens, GA<br>Office of Research and Development<br>U.S. Environmental Protection Agency<br>Athens, Georgia 30601 | | 13. TYPE OF REPORT AND PERIOD COVERED<br>Final Report<br>14. SPONSORING AGENCY CODE<br>EPA/600/01 |
| 15. SUPPLEMENTARY NOTES | | |

16. ABSTRACT

A full scale study demonstrated the potential of aeration systems to reduce the water and air pollution potential of poultry wastes under commercial conditions. The performance of two oxidation ditches, each receiving the wastes from approximately 4000 laying hens, was monitored and evaluated.

The relationships between two design and operational variables and system performance were examined. The variables were level of oxygen supply and solids retention time. It was observed that an oxygen input equivalent to the exerted carbonaceous oxygen demand provided a high degree of odor control. Increase in oxygen supply to also satisfy the exerted nitrogenous oxygen demand resulted in nitrification which terminated ammonia desorption. Subsequent nitrogen losses were the result of denitrification relationships between removals of total solids, volatile solids, COD, and organic nitrogen in aerated poultry wastes were developed.

Two major problem areas were identified and examined. The first was the removal and concentration of residual solids to maximize oxygen transfer efficiency and minimize the volume of material requiring ultimate disposal. The second was sedimentation of solids in the oxidation ditch channel which reduced and in several instances stopped mixed liquor circulation.

17. KEY WORDS AND DOCUMENT ANALYSIS

| a. DESCRIPTORS | b. IDENTIFIERS/OPEN ENDED TERMS | c. COSATI Field/Group |
|---|---|---|
| Capitalized Cost, Oxidation, Odor Control, Operating Costs, Waste Treatment, Poultry | Poultry manure, Oxidation ditch, Nitrogen transformations, nitrogen losses, liquid-solids separation, liquid aeration systems, COD removal. | 02/C/E |

| | | |
|---|---|---|
| 18. DISTRIBUTION STATEMENT<br>Release Unlimited | 19. SECURITY CLASS *(This Report)*<br>Unclassified | 21. NO. OF PAGES<br>164 |
| | 20. SECURITY CLASS *(This page)*<br>Unclassified | 22. PRICE<br>PC A08- MF A01 |

EPA Form 2220-1 (9-73)

U.S. GOVERNMENT PRINTING OFFICE: 1977-757-056/5529 Region No. 5-11